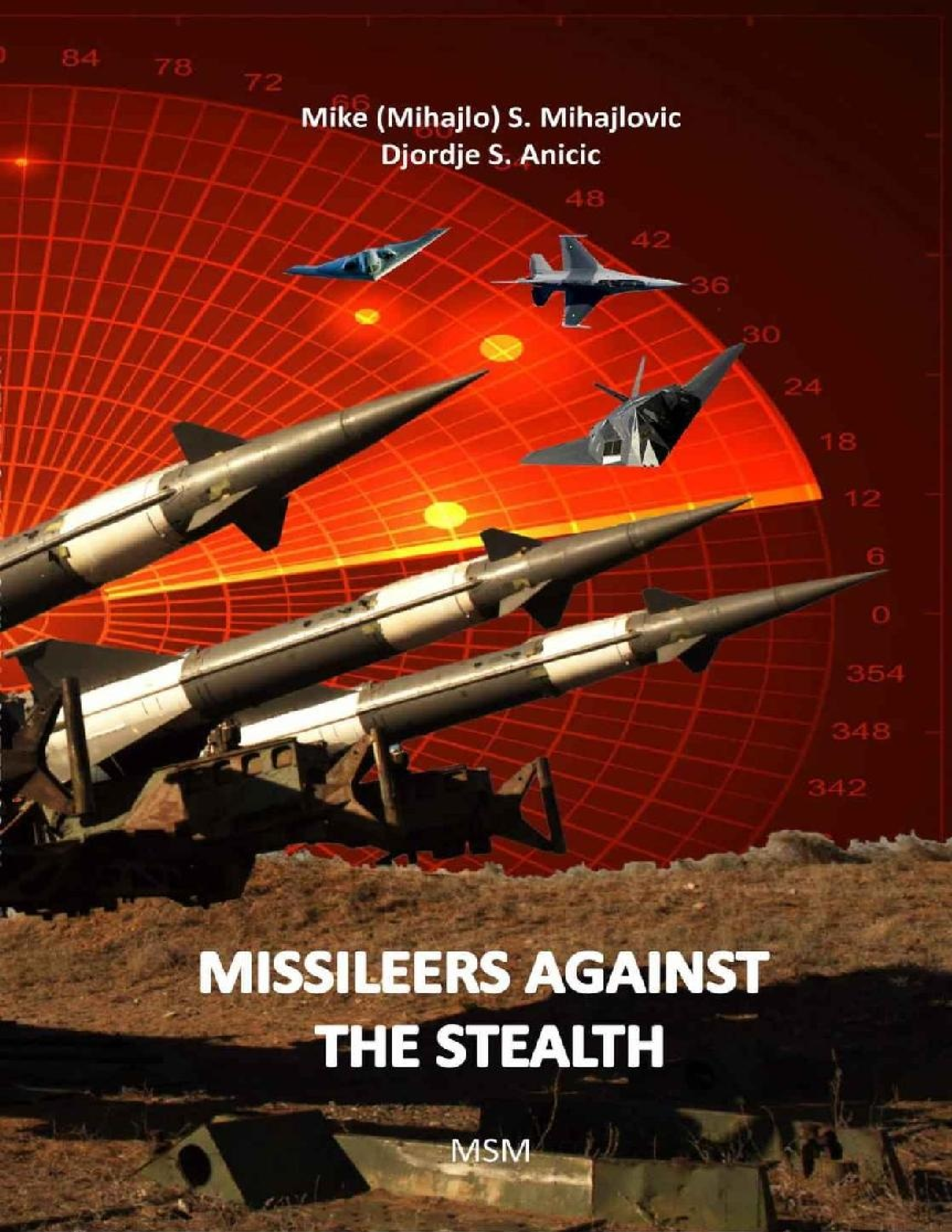

Mike (Mihajlo) S. Mihajlovic
Djordje S. Anicic

MISSILEERS AGAINST THE STEALTH

MSM

MISSILEERS AGAINST THE STEALTH

The extraordinary story of the band of maverick missileers and the first combat downing of the STEALTH aircraft in history

Mike (Mihajlo) S. Mihajlovic & Djordje S. Anicic

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"The Kosovo war is slipping down America's impressive memory hole; of course it's never discussed in the endless considerations on the 'War on Terror'. In fact, if we really cared about ending terrorism around the globe, we would explore our own actions. Milosevic claimed he was fighting terrorists. The KLA were considered terrorists by the US and the West, it was explicitly stated before our involvement. Acting to preserve our 'credibility', we armed and supported said terrorists, and demonized not only the Serbian government, but the whole people, wrecking a country that will take decades to recover, if it ever does."

Noam Chomsky

…For our families and
for those, known and unknown,
who were there…

Contents

Preface

There are many excellent books covering subjects such as radars, stealth technologies, airplanes and air defence suppression. Majority of radars and stealth technologies books are highly specialized and intended for narrow circles of professionals. Air defence materials and manuals are especially intended for end users who are usually from the military. NATO aggression on Federal Republic of Yugoslavia in 1999 is covered in few books and there are handful publications in different languages that put some of this subject together, but not a single one is combination of all previously mentioned.

The intention of this book is to describe and enlighten in detail one event that shook, shaped and steered the aviation twenty years ago. That event happened when something that was marvel in aviation been brought down with something that was, at the time of use, almost obsolete. This book took the approach firstly through the eyes of missile crew than through the eyes of pilot in the last war of 20th century where one small, independent country, in the middle of Europe, was brutally attacked by mighty alliance for the sake of political reasons that are very controversial. But this event was not just the end of experiment, rather the beginning. Definitely, in the future stealth and missile will meet many more times in the sky over some other countries.

Both authors participated in that war in the air defence and intelligence roles. Lt. Col. Anicic, as a missile battalion deputy commander and executive officer, was personally involved in downing F-117A. Because of the necessary requirements of security, both stealth and air defence materials are not widely known and there are a lot of speculations about these events, both in the printed material and also on the web. Some of them are pure imagination and some of them are close to the truth. The real truth is now known to a very narrow circle of experts but even there some the finest details are not known.

The intention of the authors was not to write a pure technical book simply because there are plenty of technical publications and manuals about the radars, stealth, missiles, air defence suppression, development programs etc. The intention was also not to just address the historical events, but rather to combine

all of that in a story which can tell both professional in their respectful field and also general public how the clash of two technologies culminated in the sky over Serbia and what are the consequences for the technology development and impacts on future of the air warfare.

One of the challenges with this type of approach is to objectively expose error without casting the slightest shadow on those who took an oath and fought for their countries. In majority of books about air warfare, there is usually an accent on one side, depends who the author is and for which audience the book is intended. Of course, majority books are related to the pilots - fighter pilots, bombers or "wild weasel" crews. This book took another approach. In this book we tried to put the reader into the cabin of the missile fire control center as well as into the aircraft cockpit. All they tried to do is to do their duty as best as they can and live to fight another day. As the operation of both missile crew and pilot are highly technical, an additional approach was made to explain the technology behind so that the ordinary reader who is not military or engineering educated can understand the complexity behind. A large number of authentic photos and illustration is used to support the text and help the reader to better understand the written material.

Why US and other NATO pilots fight, and sometimes kill opponent military personnel or even worst innocent civilians, in some places so far from home where majority of population in their own countries barely ever heard of? The short answer is that they were ordered there, and the military was at the mercy of elected government officials. It was not the decision by men in uniforms where, and whom to fight, so, having no real choice, they went and they will go. Suit and ties in Washington DC, Wall Street, Tel Aviv or London for example, makes the wars for their own interests, sometimes geopolitical sometimes economic and the soldiers just execute their orders, like them or not. For politicians there is no eternal enemies, just eternal interests. Today's enemy is tomorrows friend and vice versa…Very often "enemy of my enemy is my friend"…

On the other side, there are missile system crews. Ordinary people, professionals, like their opponents in the sky. Their job is to defend the sky over their country. All their military careers they train over and over again so that in less than 30 seconds they can bring the enemy aircraft down. That 30 seconds is all they have to do their duty or to die trying to do that. Only highly trained and motivated crew can do that and live to fight another day.

Both pilots and missile crew in reality never see the faces of their opponents. For them that is maybe monochrome picture on the screen in the cockpit with the crosshair in the middle of it where the laser bomb will hit or blimp on the radar screen and the other blimp of the missile which in a few seconds will intercept the target. Behind that building in the crosshair or that blip on the radar screen are living creatures - people with families, somebody that wait them to come back. Feelings and emotions in those few seconds before the bombs or missile launch can be understand only by those who passed through that…and those who had soul, hearts and mind to think that…

Some may find this book trivial and too simple even for an introductory text. Again, please accept apologies; the simplicity is because the authors did not include anything they couldn't understand themselves. Besides, if the book seems trivial, you're already beyond the point of need, anyway. Radar and stealth experts may be bothered by some of the approximations, but these approximations have proven to be adequate for real applications. Some readers will undoubtedly find subjects in the text for which references aren't properly cited. The author apologizes in advance for these errors, but 20 years in the black makes them difficult to correct. In addition, try as one will, there will always be mistakes that escape into the text; please notify us of those you find so that they may be corrected.

The text is oriented toward the ordinary reader who is interested in history of warfare and military technology. It also may be of interest for graduate engineers with some prior background in radar, communications, and basic physics. Intelligence community and military analysts may find interesting some of the attacking aircraft, missile batteries and search and rescue tactics and procedures. Conceptually, this book is written that every chapter can be read without the reading of the previous chapter. The reader may ask: Can this book be used to train somebody to shot down the aircraft? The answer is no! That is, by all means, not simple and high degree of training is necessary, but this book put the light on how very well-trained crews can do that. The other question: Is there a "magic bullet" how to shoot stealth airplane? The answer is again no, but there are tactical methods and procedures described in a plain way that allows trained crew to do that.

This book is a labour of love, and it represents years of labour both researching and writing.

Foreword

Neva Against the STEALTH

After the NATO intervention against Yugoslavia, a considerable number of classified and unclassified works were written in major languages analyzing the subject: How the old missile system SA-3 Goa (S-125M1 Neva) was able to track and shot down the modern aircraft considered almost as invisible to the enemy radars, the famous US Air Force F-117A, proud of US aircraft industry and scourge of the Sadam's air defence during the Gulf War. In these publications the different aspects of this events are addressed but not the single one (except maybe some highly classified analyses available only for the designated few) addresses the whole aspect in one. With this book the authors in a deep analytical way, using confirmed information, presented what happened before, during and after the event. Just a brief look into the table of contest shows that in front of us is authoritative work about the technology and tactics in the collision path which culminated in March 1999.

The reader is first introduced to the development and characteristics of radars, basis of the stealth technology and stealth program, missile guidance and development of SA-3 air defence system and anti radiation missiles as the main enemy of the missile units. What follows is the combat itself where the authors on interesting way talks about the missile crew roles as well as the opponent pilot and his views.

F-117A was, in technological way, far more advanced than the missile system and by all parameters presented before the war, it was considered invisible for the SA-3 system. Previous combat engagement greatly contributed to this aura of invincibility. This myth was crushed on night of March 27, 1999 when the first missile hit the target. What this event shows is that an obsolete missile system can be very useful if the crew who operates that system is properly trained and experienced. The combat was decided with the sole engagement of the missile crew, without any support from the brigade command or air defence network. There were no magic in the downing of stealth either. The missile system worked in own autonomous mode and it was able to detect, track, engage and destroy the aircraft who supposed to be invisible for the very same system.

The whole chapter is designated to the 3rd battalion as a winner in this duel with Stealth. This chapter in extensive manner covers the role of every member of the combat crew. It also includes training, tactical procedures, modes of readiness prior to combat engagement, regime of operations, tracking, target acquisition and much more in a very descriptive way which make the reader feels like he or she is in the missile guidance station. Of particular interests is the personal experience of Lt. Col. Anicic who was one of the commanders in the crew which downed stealth and his description of the event is priceless.

I was personally engaged in the deep analyses of this engagement and by the behaviour of every crew member, including the support units as well as the pilot (aircraft trajectory, speed, maneuver etc.) my conclusion was that the combat crew performed all tactical steps brilliantly. Commands issued to engage and stop the fire control radar in the short intervals were crucial for the safety of people and equipment denying the enemy use of antiradiation missiles. On the other hand, the pilot of F-117A performed also at the master's level so that the missile hit him almost at the end of the range.

There are many questions left unanswered especially what happened after the radar imitator emissions few hours before duel, who picked up those signals, was there any alteration of the flight pre-programmed paths after the mission over Belgrade because the stealth return flight very closely matched the directions of the radar decoy emission azimuths, what happened with the other two blimps which Lt. Col. Anicic saw on the radar screen when the target was detected, did the pilot got any warning signal that he is illuminated by the fire control radar, why pilot said that he was hit by the second missile when only the first one actually acquire the target…There are some details on which only US side may have answers…In any case, after reading this book, the reader can get the own clues.

US Air Force engaged two F-117A squadrons (24 +1). After the combat operation seized, 22 airplanes flew back to the States on their own. One was confirmed as a combat loss and replaced with the fresh one, but it is publicly unknown what happened with the other two. According to the intelligence reports, these two didn't flew to the States on their own. The question is: why?

NATO intention to destroy air defence capabilities of Yugoslav armed forces in the first few days of combat did not materialize even they were almost 600 times stronger. Yugoslav military withstood even some of the services such as

stationary air surveillance units were crippled. Older SA-3 systems also suffered losses, but the other parts of the military were virtually intact. This war was also the place were NATO exercise different approaches. A vast number of aircraft were used including strategic aviation such as B-1B, B-2 and B-52. It is ever standing question what was the big target engaged on the night of May 19/20. Was that the strategic B-2 bomber? The authors devoted the whole section describing the available facts. The one thing is sure and that this will still be the subject of speculation for the time being.

And for the end, this book presents the new light in the dark world of manipulations and speculations about the previously mentioned events and definitely it will make many of them, created by both sides, to disappear.

Vladimir Neskovic, Eng., PhD, Col (ret)

The past is not to be forgotten…it is the path into the future

Facing the past always cause emotions and personal as well as cultural questioning. Relationship to the past, especially at the Balkans, is one of the benchmarks and etalon of the social development in our society. This year is 20th anniversary of the beginning of NATO aggression on Federal Republic of Yugoslavia. That March 24, 1999 at 19:45 the air raid sirens sounded for the first time since World War II. In the next 78 days and nights the bombs rained on Yugoslavia in a military intervention without any authorization by UN security council and with the sole decision of the mightiest military alliance in the world. NATO airplanes and ships launched more than 50.000 bombs and missiles on a small and independent country. Marko Savic and Milica Rakic were just a kids when their life’s cut short in the blink of explosions and became symbols of Serbia suffering and sacrifice. These two kids and many more others became the victims of operation “Allied Force”. Bombing of Yugoslavia ended on June 10 with the UN Security Council Resolution 1244 under which Serbia keeps the sovereignty over the Kosovo and Metohija territory, but that territory became the international protectorate under the UNMIK and KFOR control, which is just another name for the occupation.

What stood between NATO bombers and civilians was Yugoslav Armed Forces. One of the units which fight this cruel war was 3rd missile battalion form 250th air-defence missile brigade. This battalion and its people are part of this book. This battalion was the one who shot down the pride of US Air Force formidable F-117A Nighthawk. The greatness of this achievement is that it used old, almost obsolete Soviet SA-3/S-125 missile system which is considered nothing more than a “sling shot” in military circles.

Yugoslav air defence is officially only air defence in the world which was able to successfully engage and bring down the stealth airplane to this date but definitely is not the last one. This shutout in the sky over Serbia was an event which secured place in history books. The myth of invincibility and invisibility (as many times the term STEALTH is interpreted in the press) is crushed on the night of March 27 when at 20:42 the missile hit the aircraft. The missile system without people to manage it is just a pile of steel and cables and these people, member of the combat crew, are the unsung heroes of this event and they rightfully deserve the place in history. We must also be objective for the enemy at that time and that was the pilots who happened to be at the wrong place and at the wrong time.

This book is an exciting story about the Soviet made air defence missile system SA-3 Goa/S-125 Neva as well as stealth technology and the collision path of these two technologies culminated on the night of March 27. The book also covers the people behind these systems. Importance of this book is that it covers the subject which is very little known and prone to endless speculations both domestically and internationally. Historic value of this book is that it in full covers the whole event without prejudice and speaks about the facts. The way how this book is written, without any doubts, it will become the foundation for future references and researches.

Both authors are experienced technical and military professionals and speaks with the full authority of their rich knowledge. Lt. Col (ret) Djordje Anicic is one of the heroes in the combat crew which detected, engaged and downed the stealth airplane, the man who was one of the combat crew commanders and the man who developed tactics and procedures which radically improved air defence. Mr Mihajlo (Michael as he is known in Canada) Mihajlovic is an expert professional engineer with vast knowledge of engineering aspects of both missile systems, radars and stealth technology as well as military experience in Yugoslav and Canadian armed forces.

Authors guide the reader with documented, analytical, expert and exciting way with the step by step approach, covering the multiple aspect, not just the combat engagement. Through the nine chapters, the authors analyzed the technical development of radars, stealth technology and missile system, combat engagements, strategy and tactics in the previous wars, background of the Kosovo crises and the duel of two opponents. The book speaks of the missile crew, the "combat shift" and virtually put the reader in the individual roles of missile system operators. The book also extensively covers the role of the stealth pilot and his views.

This book is the product of love for the military history and technology. This book is also product of years of researches and multiple challenges. The book is based on the chapters that each one can be read independently and yet each chapter supports the others and forms well organized and founded structure. It covers not only pure technical description but also strong historical aspects and backgrounds. All texts, for the first time, are based on the extensively researched materials, documents, literature and methodically very well set up with each subject covered with authors personal approach. Authors carefully compares available sources using their knowledge and experience. Through the text, a very clear authors erudition and skills in handling the complex technical issues is recognizable. They shall be prized for the style and cleanness in expressing their thoughts. Authors presented very complex issue with the clear and understandable way so that an ordinary reader, who is not into the subjects, can easy navigate through material and understand complexity of the problem.

The intention of the authors was not to write very narrow publication about missiles, stealth, radars and combat. It was rather the dive into the historical events with the deep background support which presents the problem through the multiple angles. The reader is guided through the multiple sources with the apex when those sources met over Serbia. Consequences of that event influenced and will be influencing the future air and missile defence in the wars to come. The book is written with the intention that the readers understand all challenges and complexity of the events which professional soldiers face but also have the personal touch through the eyes of the missile crews and the pilots, their fears, expectations and thoughts – fight and live to fight another day.

This book is rich in illustrations, diagrams and drawings which add the graphic visualization and support the texts. The approach of this book represents the new and inspiring way of thinking and presenting. The value of the book is

that is valuable source for the military history and can be classified as a textbook. Relevant and actual bibliography, which includes printed scientific publications, textbooks, history books and web-based material can be used for the further in-depth research of the specific subjects.

To describe the value of this book, we can't make mistake if we classify it as a deep source of information which streams to us and guide us to the new researches and the new horizons of knowledge. The past can't be forgotten – it is a path into the future.

This book presents the enormous contribution to the history and the culture of remembrances and I am recommending it with the great pleasure.

Belgrade
February 11, 2019

Vladica Tosic
Historian, politicologist and specialist for the international affairs

ORGANIZATION OF THE BOOK

This book covers four major topics:

- radars;
- low observables and low probability of intercept (LO and LPI) of radars often called STEALTH;
- air defence missile system and
- personal accounts of clash between air defence missile system and stealth airplane.

In some sections, all of them are covered, because the signatures often interact.

Chapter 1 provides an introduction and history of radars - RF/microwave LPI/LO techniques and some basic LPI/LO equations. It also includes basic explanation of electronic warfare (EW).

Chapter 2 covers stealth technology.

Chapter 3 covers missile guidance for the most common systems.

Chapter 4 surveys development of surface to air missile system SA-3 Goa/S-125 Neva and derivatives.

Chapter 5 addresses anti-radiation missiles and their use.

Chapter 6 covers SA-3 Goa/S-125 Neva system combat history.

Chapter 7 describes F-117 stealth program development.

Chapter 8 covers war and combat engagement between F-117 and Yugoslav (Serbian) SAM during NATO aggression of Yugoslavia with personal details of SAM crews, stealth pilot and other aircraft pilots and combat search and rescue teams (CSAR).

Chapter 9 deals with the aftermath of the war and consequences in stealth and air defence developments.

Researching material for this book, authors used an extensive amount of reference material and the list of sources is covered in section: Further Readings and Bibliography.

A detailed glossary of potential unfamiliar terms and abbreviation appears at the end of this book.

As always, errors tend to creep into works such as this. Although considerable effort was expended to minimize such mistakes, no claim is made as to their nonexistence. In any case, the authors have assumed full responsibility when they occur. Constructive feedback is welcome whenever an error is found or recommendations for positive changes are provided.

About the Authors

Djordje (Sava) Anicic was born 1958 in the village of Jazak, municipality of Irig, at the foothills of the Serbian mountain of Fruska Gora in the norther Serbian province of Vojvodina. He finished elementary school in Vrdnik and high school (mathematical department) in Aleksinac and Ruma. After the high school he enrolled into the Air force technical academy, air defence branch. After the graduation from the academy, he started the first commission as a 2Lt in the city of Skopje (now in Macedonia), and later in Belgrade, serving in SA-3 air defense missile units. During his service, he passed through all duties in the missile battalion from the platoon commander to the battalion XO. In a few occasions he went to the former USSR for the combat and live missile launching.

At the beginning of NATO aggression, he was 3rd battalion XO in the rank of Lt. Col. He was one the two commanders who commander the combat crew which downed F-117A on March 27, 1999. He is the record holder as an officer with the most combat hours in the entire Yugoslav air defense.

After the war, during the deep reorganization of the Yugoslav military and dismantling the 3rd battalion, he was downgraded to the position which is reserved for the officer with the lower ranks despite he was decorated buy the president. His critics of the military establishment and commanding during the war were drastically sanctioned after the war

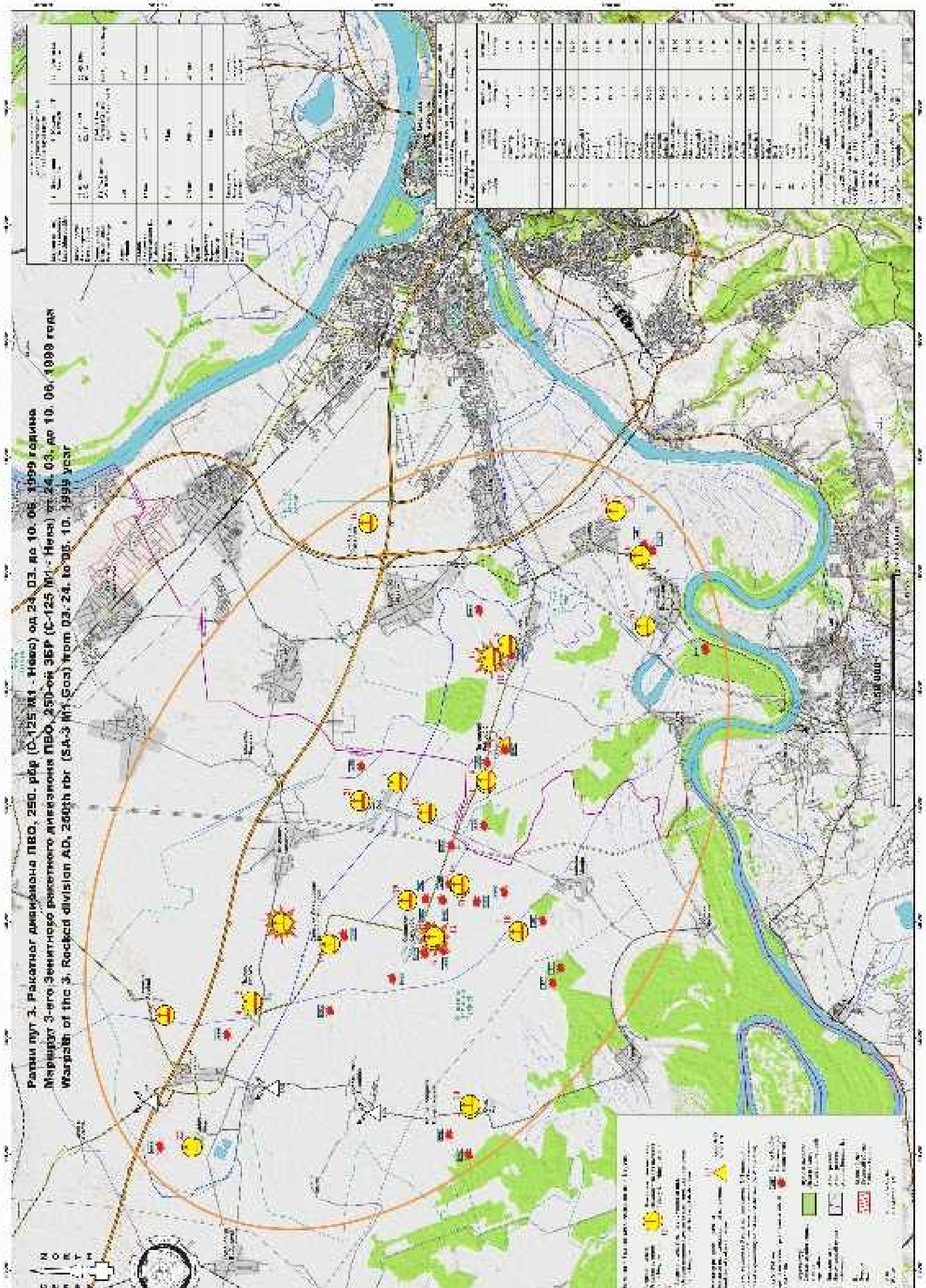
After spending less than a year at the lower rank position, he was sent to the military academy to teach the subjects of “missile unit tactics”. He was retired on his own request in 2002 after bitter struggle with the military establishment. After retiring, he decided to publish the missile battalion diary which he kept, day-by-day, during the entire war in the form of book with the title “Smena” (The Shift). Publishing this book, he disclosed all positive and negative aspects of the combat, military organization, functionality and command structure. He is contributor of the few internet portals as well often participator in TV documentaries and shows. He is also a member of the air defence veteran’s organization.

Mihajlo (Michael) (Slobodan) Mihajlovic was born in 1966, in the town of Zrenjanin, in the northern Serbian province of Vojvodina. He finished elementary school in the village of Velike Livade and Zrenjanin as well as high school (physics and natural sciences department). After the enrolment to the University of Novi Sad he was called to the compulsory military service. He served in artillery units in Bosnia. After the graduation at the Faculty of Technical Sciences, Mechanical Engineering, he worked as a teacher in the technical college and defence industry.

Since 2002 he lives and works in Canada. He has an academic degree in engineering and numerous professional certifications which includes Canadian Professional Engineering license. His progressive engineering experience is in

engineering design for the defence industry where he designed light armored vehicles, weapon platforms, radar decoys, camouflage systems and ballistic protection. Other expertise includes engineering in building sector - commercial, industrial, institutional, residential and government buildings, military bases, metallurgy plants and smelters; project development, commissioning, technology development and technical courses development and lecturing. He is the author of the book “Specilajne Snage Sveta” (The World Special Forces) published in Serbian language. Beside the book he is also the author of numerous scientific and technical articles which includes both military and non-military subjects.

His job provided him the opportunity to work all over the world, including a tour with the Canadian Forces in Afghanistan (Kandahar). He also spent three years in Canadian Forces reserve, as an officer in RC EME (Royal Canadian Electrical and Mechanical Engineers).



3rd battalion theatre of operations and combat path during the 78 days of war. The unit covered western approaches to the capital. During the war it passed more than 100.000 km, change position 23 times and was targeted with 22 antiradiation missiles.

Chapter One

RADAR

Early History of Radar

With the man desire to camouflage and hide things, it was also his desire to uncover things - measure always met with countermeasure. To detect the objects in the air, device named **RADAR**[1] has been invented. Radar is an object-detection electromagnetic system that uses radio waves for detection and location of reflecting objects such as aircraft, ships, spacecraft, vehicles, people, and the natural environment.

Radar uses the principle of sending a radar wave, which is a form of electromagnetic radiation, in a desired direction with a transmitter, and then collecting the reflected signals from a target with a receiver. Once reflected signals are received, the range to a target can be calculated by evaluating the interval of the radar signal's travel; the half time of total interval gives the distance of the target while the radar signal propagates from the transmitter and returns to the receiver after reflection from the target. Neither a single nation nor a single person is able to say, that he/she (or they) is the inventor of the radar method. One must look at the "Radar" than an accumulation of many developments and improvements earlier, which scientists of several nations parallel made share. There are nevertheless some milestones with the discovery of important basic knowledge and important inventions.

The Scottish physicist James Clerk Maxwell developed his electro-magnetic light theory (Description of the electro-magnetic waves and her propagation) in 1865. As early as 1886, German physicist Heinrich Hertz showed that radio waves could be reflected from solid objects and proves the Maxwell's theory with that. In 1895, Alexander Popov, a physics instructor at the Imperial Russian Navy school in Kronstadt, developed an apparatus using a coherer tube for detecting distant lightning strikes. The next year, he added a spark-gap transmitter. In 1897, while testing this equipment for communicating between two ships in the Baltic Sea, he took note of an interference beat caused by the passage of a third vessel. In his report, Popov wrote that this phenomenon might be used for detecting objects, but he did nothing more with this observation.

In 1904 The German high frequency engineer Christian Hülsmeyer invents

the “Telemobiloskop” to the traffic supervision on the water. He measures the running time of electro-magnetic waves to a metal object (ship) and back. A calculation of the distance is thus possible. This is the first practical radar test. Hülsmeyer registers his invention to the patent in Germany and in the United Kingdom. It operated on a 50 cm wavelength and the pulsed radar signal was created via a spark-gap. His system already used the classic antenna setup of horn antenna with parabolic reflector and was presented to German military officials in practical tests in Cologne and Rotterdam harbour but was rejected. In 1915, Robert Watson-Watt used radio technology to provide advance warning to airmen. In 1917 the French engineer Lucien Lévy invents the super-heterodyne receiver. He uses as first the denomination “Intermediate Frequency”, and eludes the possibility of double heterodyning. At the same time, Serbian - American scientist and inventor Nikola Tesla in some of his works proposed the radio waves use to detect and "follow" the objects on the sea surface. Measuring the signal traveling, the distance and direction can be determined.

During the 1920s Robert Watson – Watt went on to lead the U.K. research establishment to make many advances using radio techniques, including the probing of the ionosphere and the detection of lightning at long distances. Through his lightning experiments, Watson-Watt became an expert on the use of radio direction finding before turning his inquiry to shortwave transmission. Requiring a suitable receiver for such studies, he told the "new boy" Arnold Frederic Wilkins to conduct an extensive review of available shortwave units. Wilkins would select a General Post Office model after noting its manual's description of a "fading" effect (the common term for interference at the time) when aircraft flew overhead.

In 1921 US-American physicist Albert Wallace Hull invented the “Magnetron” as an efficient transmitting tube. In 1922 the American electrical engineers Albert H. Taylor and Leo C. Young of the Naval Research Laboratory (USA) locate a wooden ship passing through the beam path caused the received signal to fade in and out. Taylor submitted a report, suggesting that this phenomenon might be used to detect the presence of ships in low visibility, but the Navy did not immediately continue the work.

Eight years later, Lawrence A. Hyland at the Naval Research Laboratory(NRL) observed similar fading effects from passing aircraft; this revelation led to a patent application as well as a proposal for further intensive research on radio-echo signals from moving targets to take place at NRL, where Taylor and Young were based at the time.

In 1930 Lawrence A. Hyland (also of the Naval Research Laboratory), locates an aircraft for the first time. In 1931 a ship is equipped with radar. As antennae are used parabolic dishes with horn radiators. The development of the “Klystron” in 1936 by the technicians George F. Metcalf and William C. Hahn, both from General Electric will be an important component in radar units as an amplifier or an oscillator tube.

Before the Second World War, researchers in the United Kingdom, France, Germany, Italy, Japan, the Netherlands, the Soviet Union and the United States, independently and in great secrecy, developed technologies that led to the modern version of radar. Australia, Canada, New Zealand, and South Africa followed prewar Great Britain's radar development, and Hungary generated its radar technology during the war.

In France in 1934, following systematic studies on the Split Anode Magnetron, the research branch of the Compagnie Générale de Télégraphie Sans Fil (CSF) headed by Maurice Ponte with Henri Gutton, Sylvain Berline and M. Hugon, began developing an obstacle-locating radio apparatus, aspects of which were installed on the ocean liner Normandie in 1935. During the same period, Soviet military engineer P. K. Oshchepkov, in collaboration with Leningrad Electrophysical Institute, produced an experimental apparatus, RAPID, capable of detecting an aircraft within 3 km of a receiver. The Soviets produced their first mass production radars RUS-1 and RUS-2 Redut in 1939 but further development was slowed following the arrest of Oshchepkov and his subsequent gulag sentence. In total, only 607 Redut stations were produced during the war. The first Russian airborne radar, Gneiss-2, entered into service in June 1943 on Pe-2 fighters. More than 230 Gneiss-2 stations were produced by the end of 1944. The French and Soviet systems, however, featured continuous-wave operation that did not provide the full performance ultimately synonymous with modern radar systems.

Full radar evolved as a pulsed system, and the first such elementary apparatus was demonstrated in December 1934 by the American Robert M. Page, working at the Naval Research Laboratory. The following year, the United States Army successfully tested very basic surface-to-surface radar to aim coastal battery searchlights at night. This design was followed by a pulsed system demonstrated in May 1935 by Rudolf Kühnhold and the firm GEMA in Germany and then another in June 1935 by an Air Ministry team led by Robert A. Watson-Watt in Great Britain (**Figure 1-1**).

In 1935, Watson-Watt was asked to judge recent reports of a German radio-based death ray and turned the request over to Wilkins. Wilkins returned a set of calculations demonstrating the system was basically impossible. When Watson-Watt then asked what such a system might do, Wilkins recalled the earlier report about aircraft causing radio interference. This revelation led to the Daventry experiment of February 26 1935, using a powerful BBC shortwave transmitter as the source and their GPO receiver setup in a field while a bomber flew around the site. When the plane was clearly detected, Hugh Dowding, the Air Member for Supply and Research was very impressed with their system's potential and funds were immediately provided for further operational development. Watson-Watt's team patented the device in GB593017.

Development of radar greatly expanded on 1 September 1936 when Watson-Watt became Superintendent of a new establishment under the British Air Ministry, Bawdsey Research Station located in Bawdsey Manor, near Felixstowe, Suffolk. Work there resulted in the design and installation of aircraft detection and tracking stations called "Chain Home" along the East and South coasts of England in time for the outbreak of World War II in 1939. This system provided the vital advance information that helped the Royal Air Force win the Battle of Britain; without it, significant numbers of fighter aircraft would always need to be in the air to respond quickly enough if enemy aircraft detection relied solely on the observations of ground-based individuals. Also vital was the "Dowding system" of reporting and coordination to make best use of the radar information during tests of early deployment of radar in 1936 and 1937.

Given all required funding and development support, the team produced working radar systems in 1935 and began deployment. By 1936, the first five Chain Home (CH) systems were operational and by 1940 stretched across the entire UK including Northern Ireland. Even by standards of the era, CH was crude; instead of broadcasting and receiving from an aimed antenna, CH broadcast a signal floodlighting the entire area in front of it, and then used one of Watson-Watt's own radio direction finders to determine the direction of the returned echoes. This fact meant CH transmitters had to be much more powerful and have better antennas than competing systems but allowed its rapid introduction using existing technologies.

During World War II a key development was the cavity magnetron in the UK, which allowed the creation of relatively small systems with sub-meter

resolution. Britain shared the technology with the U.S. during the 1940 Tizard Mission.

In April 1940, Popular Science showed an example of a radar unit using the Watson-Watt patent in an article on air defence. Also, in late 1941 Popular Mechanics had an article in which a U.S. scientist speculated about the British early warning system on the English east coast and came close to what it was and how it worked. Watson-Watt was sent to the U.S. in 1941 to advice on air defence after Japan's attack on Pearl Harbor. Alfred Lee Loomis organized the Radiation Laboratory at Cambridge, Massachusetts which developed the technology in the years 1941 - 45. Later, in 1943, Page greatly improved radar with the monopulse technique that was used for many years in most radar applications.

Radar Fundamentals

Radar, as previously described, is an acronym for Radio Detection and Ranging, which tends to suggest that it is a piece of equipment that can be used to detect and locate a target. Modern radar does much more than just detection and ranging. It is used to determine the velocity of moving targets and also find out many more characteristics about the target such as its size, shape and other physical features including, for example, the type and number of engines used on an aircraft. Radar is extensively used in many civilian and military applications. Radar has been and will continue to be an essential capability for militaries worldwide. This chapter gives a comprehensive treatment to the radar fundamentals covering a wide cross-section of topics including basic radar functions, related performance parameters, radar range equation, radar waveforms, radar transmitters, receivers and displays, radar antennas and types of radar.

Radar System and Radar Range

Through this book, the minimal use of equations and formulas will be used. In some instances they are included because it is easier to understand the matter.

The radar equation describes the performance of radar for a given set of operational, environmental, and target parameters.

Radar is a standalone active system with its own transmitter and receiver. It is primarily used for detecting the presence and finding the exact location of a far-off target. It does so by transmitting electromagnetic energy, in the form of short bursts in most of the cases, and then detecting the echo signal returned by the target.

The radio waves used by radar are produced by a piece of equipment called a magnetron. Radio waves are similar to light waves: they travel at the same speed, but their wavelengths are much longer and have much lower frequencies (**Figure 1-2**). Light waves have wavelengths of about 500 nanometers (500 billionths of a meter, which is about 100 - 200 times thinner than a human hair), whereas the radio waves used by radar typically range from about a few centimeters to a meter the length of a finger to the length of your arm or roughly

a million times longer than light waves. Both light and radio waves are part of the electromagnetic spectrum, which means they are made up of fluctuating patterns of electrical and magnetic energy zapping through the air. The waves a magnetron produces are actually microwaves, similar to the ones generated by a microwave oven. The difference is that the magnetron in radar has to send the waves many miles, instead of just a few inches, so it is much larger and more powerful (**Figure 1-3**).

The range of the intended target is computed from the time that elapses between the transmission of energy and reception of echo. The location of the target can be determined from the angle/direction of arrival of the echo signal by using a scanning antenna, preferably transmitting a very narrow width beam. As mentioned in the introductory paragraph, radar today does much more than just detecting a target and finding its location. Radar can be used to determine the velocity of a moving target, track a moving target and even determine some of the physical features of the target. Of course, no single radar type can be used to perform all the functions. There are different types which are best suited to different applications. In addition, radar is a principal source of navigational aid to aircraft and ships. It forms a vital part of an overall weapon guidance or a fire-control system. Behind most of the radar functions lies its capability to detect a target and find its range and velocity.

The basic components of a radar system are shown in the block-schematic arrangement in **Figure 1-4**.

The radar signal waveform as generated by the waveform generator modulates a high-frequency carrier and the modulated signal is raised to the desired power level in the transmitter portion. The transmitter could be a power amplifier employing any of the micro wave tube amplifiers such as Klystron, Travelling Wave Tube (TWT), Crossed Field Amplifier (CFA) or even a solid-state device. The radar waveform is generated at a low power level, which makes it far easier to generate different types of waveforms required for different radars.

The average output power requirement of radar could be as small as a few tens of mill watts for very short-range radars to several megawatts for Over-The-Horizon-Radar (OTHR). The duplexer allows the same antenna to be used for both transmission as well as reception. It acts as a switch disconnecting the receiver from the antenna during the time the relatively much higher power

transmitter is ON to protect the receiver from getting damaged. On reception, the weak received signal is routed to the receiver by the duplexer. The duplexer usually makes use of gas filled transmit/receive tubes that are basically sections of transmission line filled with a low breakdown voltage gas. These tubes get fired due to presence of high power to direct the transmitter output to antenna. After the transmitter signal is radiated, these tubes de-ionize or recover quickly to direct any received signal to the receiver input. A circulator is sometimes used to provide further isolation between transmitter and receiver. A circulator as a component can also be used as a duplexer. The circulator duplexer contains a high-power RF circulator comprising of signal couplers and phase shifters such that a signal entering one port has a low attenuation path only to the next port in a particular direction. All other paths are high attenuation paths (**Figure 1-5**).

The antenna acts as an interface between the radar transmitter output and free space. Mechanically steered parabolic reflector antennas and electronically steered antenna arrays are commonly used. The echo signal received by the antenna is directed to the receiver input. The receiver is usually of the super heterodyne type. The receiver filters out-of-band interference. It also amplifies the desired signal to a level adequate for operating subsequent circuits (**Figure 1-6**, **Figure 1-7**).

The purpose of signal processing is to reject the undesired signals such as clutter and enhance the desired signals due to the targets. It is done prior to the section that makes the decision as to whether the target is present and in case of target being present, extracts the information such as range, Doppler and so on. Data processing refers to the processing done after the detection decision has been made.

Radar clutter is nothing but unwanted echoes. These undesired echoes could originate from a number of sources such as land or sea surfaces, insects, animals or birds, weather conditions like rain or atmospheric turbulences, objects deployed as countermeasures like chaff and decoys and so on. Clutter may be divided into three broad categories, including surface clutter originating from objects on land and sea surfaces; volume clutter produced by chaff and weather conditions such as rain and clutter originating from point targets such as birds, animals, vehicles and structures. The term ‘clutter’ to an extent is application specific. Clutter in one application may be a genuine target in another. For example, for radar tracking a land target such as tank to guide a missile to hit the target, scattering from vegetation on land surface or from weather conditions

such as rain would be clutter. On the other hand, for airborne remote sensing radar, reflection of radar energy from natural vegetation is the primary target. Also, backscattering from atmospheric particles and turbulences would be a genuine signal for weather radar.

Surface clutter includes both ground clutter and sea clutter. The magnitude of clutter, that is, the magnitude of undesired radar signal backscattered in the direction of radar depends upon the nature of material composition, surface roughness and the angle the radar beam makes with the surface in azimuth and elevation directions. The backscattered radar energy is also a function of radar signal wavelength and polarization. The reflected signal is the phasor sum of reflections from a large number of individual scatterers. These individual sources of scatter may be static such as in the case of buildings, tree trunks and so on, or moving like in the case of rain drops, leaves or ripples on the sea surface. Individual sources of clutter vary spatially and temporally.

Functions like automatic tracking, target recognition are examples of data processing in a radar system. The display puts the processed information in a form usable by radar operators and others wanting to use the information such as air traffic controllers, weapon system operators and so on. The operation of radar and the sequence of events that take place from start to finish can be summarized in case of typical pulsed radar as follows.

The transmitter generates a repetitive pulse train with each pulse having a burst of RF signal. The pulse parameters, of course, vary with the type of radar and the mode in which it is operating. The duplexer routes the pulsed electromagnetic energy to the transmitting antenna which concentrates the energy fed to its input into a narrow beam in the direction of the intended target. At the same time, a time base is initiated coinciding with the transmission time instant of the pulse. The electromagnetic wave propagates through the atmosphere. This wave gets reflected from the target due to difference in the impedance characteristics of the targets. The impedance offered by the atmosphere (or more precisely, the free space) to the propagating electromagnetic wave is 377 Ω (Ohm) and any discontinuity encountered causes the wave to get reflected. The amount of reflection depends upon the characteristics of the target. The target reflects the wave in all directions and the portion of the reflected energy travelling in the direction of the radar constitutes the echo or the backscatter.

It may be mentioned here that the reflection also occurs from ground and sea surfaces, atmospheric conditions like clouds, turbulence and so on. These reflections occurring in the direction of the radar constitute clutter. The backscatter energy travels back to the radar and a portion of it along with a portion of the clutter is intercepted by the radar's receiving antenna, which in the present case is same as the transmitting antenna. The amount of the backscatter energy intercepted by the antenna depends upon the capture area of the antenna. The received signal is routed to the receiver by the duplexer. The signal that contains both the desired echo as well as the interfering signals and noise gets processed in the receiver.

The processed information is then subjected to the detection threshold comparison and if the signal is larger than the detection threshold, detection is said to occur. lf the detection is caused by the desired target, a target is said to be present and if the same occurs due to interfering signals, detection is a false alarm. The detection threshold in fact is so chosen as to minimize the probability of false alarm. Another detection error is the one when the radar fails to detect an existent target due to the target echo signal being weak and being not able to cross the detection threshold. When detection occurs, that is, when the processed signal crosses the detection threshold, the time base initiated at the start is strobed and the round-trip propagation time measured to determine the target range. The antenna's position encoders are also strobed to determine the angle-of-arrival of the echo at the time of detection. If the target is a mobile one, its radial velocity information is contained in the Doppler shift, which can be used to determine the target velocity.

Radar Range Equation

The radar range equation relates the radar's detection range to various radar and target parameters (**Figure 1-8**). These parameters include the transmitted power, transmit antenna gain, radar cross-section of the target, receive antenna aperture, minimum detectable power at the receiver input and various loss factors. The range equation has been derived from first principles step-by-step in the following paragraphs. A brief description of different parameters entering the range equation has also been given along with different steps of derivation of equation, in particular, emphasizing the significance of these parameters vis-a-vis the maximum detection range of the radar.

One form of the basic radar range equation is:

$$SNR = \frac{P_S}{P_N} = \frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 R^4 k T_0 B F_n L}$$

Where:

- SNR is termed the signal-to-noise ratio and has the units of watts/watt, or w/w.
- P_S is the signal power at some point in the radar receiver – usually at the output of the matched filter or the signal processor. It has the units of watts (w).
- P_N is the noise power at the same point that is specified and has the units of watts.
- P_T is termed the peak transmit power and is the average power when the radar is transmitting a signal. P_T can be specified at the output of the transmitter or at some other point like the output of the antenna feed. It has the units of watts
- G_T is the directive gain of the transmit antenna and has the units of w/w.
- G_R is the directive gain of the receive antenna and has the units of w/w. Usually, $G_T = G_T$ for monostatic radars.
- �� is the radar wavelength and has the units of meters (m).
- �� is the target radar cross-section or RCS and has the units of m^2.
- R is the range from the radar to the target and has the units of meters.
- k is Boltzman's constant and is equal to $1.38x\ 10^{-23}$ w/(Hz ^{0}K)

- T_0 denotes a reference temperature in degrees Kelvin. We take and usually use the approximation $kT_0 = 4 \times 10^{-21}$ w/Hz
- B is the effective noise bandwidth of the radar and has the units of Hz.
- F_n is the radar noise figure and is dimensionless, or has the units of w/w.
- L is a term included to account for all losses that must be considered when using the radar range equation. It accounts for losses that apply to the signal and not the noise. L has the units of w/w. L accounts for a multitude of factors that degrade radar performance.

When radar transmitter and receiver are located at the same location, then it is referred monostatic radar. In some cases, the radar transmitter and receiver can be at the different locations when viewed from the target and this is referred as bistatic radar. The third classification is when the two antennas are located at the same site just slightly separated. This is referred as quasi static.For monostatic system a single antenna is generally used to transmit and receive the signal.

$$P_t = \frac{P_r G_t}{4\pi r^2} \sigma \frac{A_{eff}}{4\pi x r^2}$$

P_t = power transmitted by the radar (watts)
G_t = gain of the radar transmit antenna (dimensionless)
r = distance from the radar to the target (meters)
σ = radar cross section of the target (meters squared) - RCS
A_{eff} = effective area of the radar receiving antenna (meters squared)
P_r = power received back from the target by the radar (watts)

In practice, the radar receiver will sense a nonzero signal even when there is no target present. This other sources can come as a clutter, interference or noise.

Clutter is reflections from the ground, foliage, and other objects in the environment result in signals back to the radar receiver. Interference are signals from other electronic systems that when radiate will be received. Their intended purpose might be to intentionally distract the radar (i.e., a jammer) or they may be unintentional interferers that occupy the same frequency band (e.g., radio stations, other radars, etc.). The noise is the thermal motion of electrons gives rise to random voltages and currents. Surprisingly, for well-designed radar operating at microwave frequencies, thermal noise generated in the radars receive channel can be the limiting factor in detecting a low observable target.

Detection Range

One of the important uses of the radar range equation is in the determination of detection range, or the maximum range at which a target has a given probability of being detected by the radar. The criterion for detecting a target is that the SNR be above some threshold value. If we consider the above radar range equations, we note that SNR varies inversely with the fourth power of range. This means that if the SNR is a certain value at a given range, it will be greater than that value at shorter ranges. The upshot of this discussion is that we define the detection range as the range at which we achieve a certain SNR. In order to find detection range, we need to solve the radar range equation for.

$$R = \left(\frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 (SNR) k T_0 B F_n L} \right)^{1/4} \text{ m}$$

The Antenna

The purpose of the radar antenna is to concentrate, or focus, the radiated power in a small angular sector of space. In this fashion, the radar antenna works much as the reflector in a flashlight. As with a flashlight, a radar antenna doesn't perfectly focus the beam. As the electromagnetic wave from the target passes the radar, the radar antenna captures part of it and sends it to the radar receiver.

The guided electromagnetic waves look more appropriate when the feeder connecting the output of the transmitter and the antenna or the input of the receiver and the antenna is a waveguide, which is generally true when we talk about microwave frequencies and microwave antennas. In case of other antennas such as those at high frequency (HF) and very high frequency (VHF), the term guided electromagnetic waves mentioned previously would be interpreted as a guided electromagnetic signal in the form of current and voltage. Sometimes, an antenna is considered a system that comprises everything connected between the transmitter output or the receiver input and free space. This includes, in addition to the component that radiates other components such as the feeder line, balancing transformers and so on. An antenna is a reciprocal device, that is, its directional pattern as receiving antenna is identical to its directional pattern when the same is used as a transmitting antenna provided; of course, it does not employ unilateral and nonlinear devices such as some ferrites. Also, reciprocity applies, provided the transmission medium is isotropic and the antennas remain in place with only transmit and receive functions interchanged. Antenna reciprocity also does not imply that antenna current distribution is the same on

transmission as it is on reception.

When a radio frequency (RF) signal is applied to the antenna input, there is current and voltage distribution on the antenna that lead to the existence of an electric and a magnetic field. The electric field reaches its maximum coincident with the peak value of the voltage waveform. If the frequency of the applied RF input is very high, the electric field does not collapse to zero as the voltage goes to zero. A large electric field is still present. During the next cycle, when the electric field builds up again, the previously sustained electric field gets repelled from the newly developed field. This phenomenon is repeated again and again and we get a series of detached electric fields moving outwards from the antenna. According to laws of electromagnetic induction, a changing electric field produces a magnetic field and a changing magnetic field produces an electric field. It can be noticed that when the electric field is at its maximum, its rate of change is zero and when the electric field is zero, its rate of change is maximum. This implies that the magnetic field's maximum and zero points correspond to the electric field's zero and maximum points, respectively. That is, the electric and magnetic fields are at right angles to each other and so are the detached electric and magnetic fields. The two fields add vectorially to give one field that travels in a direction perpendicular to the plane carrying mutually perpendicular electric and magnetic fields.

The common types of antenna radiation patterns include the (1) omnidirectional (azimuth plane), beam, (2) pencil beam, (3) fan beam and (4) shaped beam. The omnidirectional beam is commonly used in communication and broadcast applications for obvious reasons. The azimuth plane pattern is circular, and the elevation pattern has some directivity to increase the gain in horizontal directions. A pencil beam is a highly directive pattern whose main lobe is confined to within a cone of a small solid angle and it is circularly symmetric about the direction of maximum intensity. This is mainly used in the engagement, guiding and target tracking radars (fire control radars). A fan beam is narrow in one direction and wide in the other. A typical application of such a pattern would be in search or surveillance radars in which the wider dimension would be vertical and the beam is scanned in azimuth. The last application would be in height-finding radar where the wider dimension is in the horizontal plane and the beam is scanned in elevation. There are applications that impose beam-shaping requirements on the antenna. One such requirement, for instance, is to have a narrow beam in azimuth and a shaped beam in the elevation such as in case of air search radar (**Figure 1-9**).

The typical antenna in the older surface to air missile systems is curved so it focuses the waves into a precise, narrow beam, but radar antennas also typically rotate so they can detect movements over a large area. The radio waves travel outward from the antenna at the speed of light 300,000 km (186,000 miles) per second) and keep going until they hit something. Then some of them bounce back toward the antenna in a beam of reflected radio waves also traveling at the speed of light. The speed of the waves is crucially important. If a target is approaching at over 3,000 km/h (2,000 mph), the radar beam needs to travel much faster than this to reach the plane, return to the transmitter, and trigger the alarm in time. If in example, the target is 160 km (100 miles) away, a radar beam can travel that distance and back in less than a thousandth of a second.

As the antenna is the emitter of electromagnetic waves, it is primary target for the anti-radiation missiles such as HARM which were guided to the electromagnetic sources. More of this can be found in the Chapter 5 describing the anti-radiation missiles.

Radar Displays

Some of the more commonly used radar displays in the military radars include the A-Scope or A-Scan, B-Scope, F-Scope and Plan Position Indicator (PPI). Each one of these is briefly described in the following paragraphs. Of particular interest are the last two because most of the Soviet made radar system in air defence applications.

Plan Position Indicator (PPI)

This is an intensity modulated map like circular display that gives target location in polar coordinates. The radar location is in the centre of the display. The target range is represented by the radial distance from the centre and the target's azimuth angle is given by the angle from the top of the display, usually north, clockwise. In some types of PPI display called Offset or Sector PPI, the radar location is offset from the centre of the display. This is commonly used in search radars (**Figure 1-10**, **Figure 1-11**).

F-Scope

Horizontal and vertical axes of an F-scope display represent azimuth and elevation track error, respectively. Often it is marked as "Fi" from the Greek letter "φ". The centre of the display indicates the antenna's beam axis location. The blip's displacement from the centre indicates target's position with respect to the antenna beam axis (**Figure 1-12**).

Radar Classification

Radars can be classified on the basis of:

1. operational frequency band,
2. transmit wave shape and spectrum,
3. PRF class and
4. intended mission and mode.

Operational Frequency Band

Radars typically operate in frequency range of a few tens of MHz to few tens of GHz. Radars operating up to about 30 MHz make use of ionospheric reflection as a means to detect targets lying beyond the radar horizon. Over-The-

Horizon-Radar (OTHR) belongs in this category. Very long-range early warning radars are found in the VHF and UHF bands (30 MHz to 1 GHz).

- L band (D Band in the new designation) radars operating in the 1–2 GHz frequency band are usually long-range military radars and air traffic control radars.
- S band (E/F band in the new designation) radars operating in the 2–4 GHz band are usually the
- medium-range ground-based and shipboard search radars and air traffic control radars.
- C band (G Band in the new designation) radars operating in the 4–8 GHz frequency band are usually search and fire-control radars of moderate range, weather detection radars and metric instrumentation radars.
- X band (I/J band in the new designation) radars operating in the 8–12.5 GHz frequency band are mostly airborne multimode radars.
- Ku, K and Ka bands (J, K and L bands in the new designation) operating in the 12.5–18 GHz frequency band (Ku), 18–26.5 GHz frequency band (K) and 26.5–40 GHz frequency band (Ka) are used for short-range applications due to severe atmospheric attenuation in these bands. These include short-range terrain avoidance and terrain following radars and space based radars.
- Radars operating in the infrared and visible bands (Laser radars) are mainly used as Rangefinders and Designators.

Transmit Wave Shape and Spectrum

Based on the transmit wave shape and spectrum, radars are classified as unmodulated CW radar capable of finding target velocity only, modulated CW radar capable of finding both range and velocity, gated CW pulsed radar and modulated pulsed radar. FM-CW radars belong to the class of modulated CW radars. Pulse Doppler radar is a popular type belonging to the category of gated CW pulse radars. Pulse compression radar falls in the category of modulated pulse radar.

PRF Class

Based on PRF class, we have Low PRF radars including Moving Target Indicator (MTI) and Moving Target Detector (MTD), High PRF radars such as Pulse Doppler radar and Medium PRF radars.

Intended Mission and Mode

Radars with surface-to-surface mission are usually short-range radars that do not use Doppler.

There are many functions and types of radar. Radars with surface-to-air missions include surveillance radar, early warning radar, weather radar, fire-control radar, metric instrumentation radar, OTHR and so on. Radars with air-to-surface mission include terrain following and avoidance radars, synthetic aperture radars (SAR), ground mapping radars, radar altimeter and so on.

Basic Radar Functions

The basic functions that radar can perform include target detection, identifying target location in range and angular position and determining target velocity. The radar performs these tasks provided that the target echo signals after signal processing are sufficiently stronger than the interfering signals like noise generated in the receiver; clutter that is unwanted signal echo due to reflections from land, sea, clouds and so on; a jamming signal, which is an intentional interference; electromagnetic interference (EMI), which is an accidental interference from friendly sources such as communication systems, other radars and spillover, which is due to leakage from transmitter into receiver occurring mainly in CW radars. It may also be mentioned that not all radars are capable of measuring all these listed parameters.

Target Detection

Detection is the process of determining whether or not a target is present. There are four possible conditions of detection. If a target is present and detection also occurs, the result is considered correct. Similarly, if there is no target and the radar display also shows no detection condition, the result is again correct. If the target is present and radar fails to show it on display, an error is said to occur. But if the target is absent and radar shows detection, it is a different form of error referred to as a false alarm. Both of the last two conditions are error conditions; the one of false alarm is usually considered far more serious and undesirable. Such a tricky situation usually occurs because the target echo and interference signals have more or less the same shape after they have been processed in the receiver and only way to discriminate between the two is by amplitude comparison. The radar can often confuse between a weak target and a strong interference residue. For this reason, detection can only be described by probabilities; the probability of detection and probability of false alarm.

Target Location

The target location is expressed in terms of its range, azimuth angle and elevation angle. Range is the shortest distance of the target from the radar regardless of direction. Azimuth angle is the angle between the antenna beam's projection on the local horizontal and some reference. The azimuth reference in case of land-based radars is usually the true north. Ship-borne radars usually reference the ship's head, which is a line parallel to the ship's roll axis. Airborne radars reference the roll axis on the local horizontal plane. Elevation angle is the angle between radar antenna's beam axis and the local horizontal. Local horizontal in case of land-based radars is the plane passing through antenna's centre of radiation and perpendicular to Earth's radius passing through the same point. For ship- and airborne radars, it is also the plane containing the vehicle's pitch and roll axes.

Military Applications of Radar Systems

Though radar systems are extensively used in a wide range of civilian applications in the areas of science, meteorology and air traffic control, use of radars by law enforcement agencies and military applications outnumber all other radar applications. Major radar systems in use by the armed forces and law enforcement agencies include the police radar used for detecting traffic rule violations, surveillance-based radar systems including battlefield surveillance radar, ground penetration radar, air surveillance radar and tracking based applications such as air defence radar, weapon locating radar and ballistic missile defence radar. Military radars are also used for navigation, weather forecasting and Identification Friend or Foe (IFF). This chapter will discuss only the application of the radars in the air defence.

Surveillance-Based Applications

Surveillance radar sensors are used to monitor activity surrounding critical and/or strategic assets such as military installations, border crossings, airports, ports and harbours, nuclear research and nuclear power generation facilities, missile and satellite launch stations, oil refineries, ammunition storage depots and so on. Surveillance functions may include intended targets underneath ground level, on ground level or in the air space surrounding the critical asset. There are primary radars and secondary surveillance radars. Both types were discussed at length in Chapter 2. While primary radar systems measure only the range and bearing of intended targets by detecting the transmitted radio frequency signal reflected off the target, secondary surveillance radar (SSR)

relies on targets equipped with a radar transponder that replies to each interrogation signal by transmitting a response containing encoded data. Air traffic control (ATC) radar is an example of secondary surveillance radar system. ATC radar not only measures the range and bearing of the aircraft, it also requests additional information from the aircraft itself such as its identity and altitude. The IFF system is another example of an SSR system. Common surveillance-based military radar systems include ground (or area) surveillance radar, air surveillance radar and ground penetration radar (GPR).

State-of-the-art ground (or area) surveillance radar scans track movements of targets such as an individual walking or crawling towards a facility with precision, speed and reliability. Such radars typically have ranges of several hundred metres to over 10 km. Battlefield surveillance radar is the most commonly used application of ground surveillance. These radars are generally suit case sized tripod-mounted portable systems. Those with longer ranges are mounted on a vehicular platform. There are hundreds of other ground surveillance radars with similar or enhanced features available from major international manufacturers of Defence and security equipment.

Military application of air surveillance radar primarily involves monitoring the airspace to detect hostile aircraft and directing defensive measures against them. Conventional air surveillance radar called two-dimensional (2D) radar measures the location of a target in two dimensions including range and azimuth. Air surveillance radar capable of determining the elevation angle in addition to the target range and azimuth angle is known as three-dimensional (3D) radar. The elevation angle allows computation of target height. The 3D air surveillance radar measures range in a conventional manner but has an antenna that is mechanically or electronically rotated about a vertical axis to obtain a target’s azimuth angle and has either fixed multiple beams in elevation or a scanned pencil beam to measure its elevation angle. There are other types of radar such as the electronically scanned phased arrays and tracking radars that measure the target location in three dimensions. It is essential for air surveillance radar to be able to look around the corners to provide better coverage and capability to detect ground-hugging airborne targets. Over-the horizon-radar (OTHR) exploits certain features of Earth’s atmosphere enabling it detect low-flying aircraft over ranges of thousands of kilometres. Air surveillance radars are generally located on elevated platforms to maximize coverage area. Coverage area and capability to detect ground hugging aircraft can be further enhanced by mounting radar on an airborne platform. The Airborne Warning and Control System (AWACS) is

one such example. State-of-the-art air surveillance radars are designed to detect, locate, track and classify a wide range of targets including traditional fixed and rotary-wing aircraft, non-traditional targets like ultra-lights, Para Gliders and Unmanned Aerial Vehicles (UAVs: also referred to as drones), ballistic missiles and even birds, thereby providing early warning, situational awareness and tactical ballistic missile surveillance and defence. Radars used by air traffic controllers for both approach phase surveillance and on-route surveillance are also examples of air surveillance radars.

Tracking Radar-Based Applications

Tracking radar detects and follows the intended targets so as to determine their trajectory, a function that is put to use in a wide range of civilian and military applications. One such widely used application of tracking radar is for air traffic control. Air traffic controllers rely on systems installed both at airports as well as at strategic spots on the ground beneath air traffic lanes for effective air traffic control extending to hundreds of kilometres. Tracking radars installed at airports are generally short-range radars that are intended to track airplanes, vehicles and even individuals on the surface in and around the airport. There is a large number of military applications that rely for their functioning on tracking radars. Armed forces use tracking radars to keep track of friendly and enemy platforms, which include land-based vehicles such as tanks, airborne targets such as aircraft, unmanned aerial vehicles, missiles, rockets and ships. Radar is used to monitor enemy targets to determine if they represent an immediate threat. In case of an imminent threat, radar may track the target and then use the track information to employ suitable defensive or offensive countermeasures such as using guided missiles or aircraft to intercept the enemy targets. Another important application of tracking radars is in removal of space debris. Space debris comprises used rocket stages and leftovers from completed missions, fragmented and inactive satellites and asteroids. Tracking radar may be used to track the space debris to determine if it poses any threat to major space assets such as space stations. The spacecraft may be maneuvered to get out of the way in the case of any possibility of collision. Common military radars employing tracking radar concept or a combination of tracking and surveillance concepts include fire-control radar, weapon locating radar also called counter-battery radar or shell tracking radar.

Engagement and fire-control radar is a “tracking radar” specifically designed for integration with air-defence weapon systems. The radar component of the platform measures the coordinates of the intended target or targets in terms of

their azimuth, elevation, height, range and velocity, which may be used to determine the target trajectory and to predict its future position. These radars provide continuous position data on a single or multiple targets enabling the associated guns or guided weapons to be directed and locked on to targets.

Radar Cross Section and Reduction Methods

RCS of a target, denoted by "σ", is measured as a ratio of the transmitted radar signal power backscattered from the target per unit solid angle in the direction of radar to the radar signal power intercepted by the target. Conceptually, RCS is measured by comparing strength of reflected signal from the target to the reflected signal from a perfectly smooth conducting metal sphere with a frontal or projected area of $1m^2$. RCS is measured in m^2 and is therefore the projected area of an isotropically radiating perfectly conducting sphere that would reflect the same power in the direction of radar as the one that is actually reflected by the target for a given incident power. RCS is also measured in dBsm (or dBm^2), which is decibels relative to $1m^2$. RCS in dBsm or dBm^2 is expressed as $10 \log \sigma$ where σ is RCS in m^2 (**Figure 1-13**).

A sphere is used for comparison while computing RCS as a sphere projects the same area irrespective of its orientation. Also, RCS of a sphere is independent of frequency provided that the operating wavelength is much smaller than both the range as well as the radius of the sphere. Most structures including a sphere exhibit different RCS dependence on operating frequency.

Radar cross-section of target is influenced by both radar signal parameters such as operating wavelength and polarization as well as target characteristics such as size, shape, orientation and so on. Important factors that influence radar cross-section include the following:

- Target size and shape and surface roughness
- Target material composition with reference to its electromagnetic properties
- Relative size of target in relation to operating wavelength
- Target orientation.

Target Size and Shape

RCS is directly proportional to target size. Larger the target, greater is its RCS value. In addition to the absolute size of the target, its shape also influences

the RCS. Different shapes present different incident angles to the radar signal. Radar waves that make large angles of incidence are reflected away from the direction of the radar and therefore contribute to reducing the RCS. Very large incidence angles produce equally large angles of reflection leading to forward scattering. This makes the target stealthier. For example, the F-117A Nighthawk fighter aircraft by Lockheed–Martin is designed to have flat and large angled surfaces, which significantly contributes to its having a low RCS. The RCS of F-117A stealth fighter is estimated to be between 10 cm^2 and 100 cm^2. Similarly, air frame shaping such as alignment of planform edges and fixed-geometry S-ducts (or serpentine inlets) that prevent line-of-sight of the engine faces from any exterior view in F-22 Raptor fighter aircraft are important factors that give it an extremely low RCS of 1 cm^2 (**Figure 1-14**, **Figure 1-15**).

Indentations present in relief in a surface such as those arising from open bomb bays, ordnance pylons, joints between constructed sections and engine intakes are potent corner reflectors contributing toward increase in RCS form many orientations. It is more so as it is impractical to coat these surfaces with radar absorbent materials.

Target Material

The materials used in the construction of the target and also the materials used to coat the surfaces play a significant role in determining the RCS. There are materials such as metals that are strong reflectors of radar waves. Even a thin layer of metal coating makes the object a strong reflector of radar energy. Chaff that is often made of metallized plastic or glass is a good example. There are materials such as wood, plastic, and fibre glass that are less reflective. Use of radar absorbent materials significantly reduces the RCS. The F-117A nighthawk stealth fighter and the bomber B-2 are well-known examples of stealth technology that minimize RCS by using both aerodynamic geometry and radar absorbent materials applied to the surface of their fuselages. Radar absorbent materials minimize the reflection of radar waves thereby reducing the RCS. There are two broad categories of radar absorbing materials; namely impedance matching absorbers and resonant absorbers. There are other absorbing material configurations that have features of both the classifications.

Operating Wavelength

RCS is strong function of operating frequency or wavelength. There are three frequency regimes, namely the low frequency or Rayleigh regime, mid-frequency or Mie regime and high-frequency or optical regime. RCS is a

function of relative size of target with respect to operating wavelength and is approximately equal to the real area of the target when the target size is much smaller than the operating wavelength. For a target size roughly equal to the operating wavelength, the RCS may be greater or smaller than the real area depending upon operating wavelength before it approaches the real value in the optical region.

Target Orientation

Target orientation with respect to radar line-of-sight strongly influences the RCS. For example, a fighter aircraft presents a much larger area when viewed from the side than when it is viewed from the front. The fact that military targets such as fighter aircraft have many reflecting elements and shapes and also that targets move relative to radar line-of-sight, relative orientations of various reflecting elements and shapes on the target structure make RCS dependence on target orientation a very complex phenomenon.

Estimated radar cross section for some targets*:

Target	Radar Cross Section (RCS) m^2
Cruiser (length 200 m)	14000
B-52 Stratofortress	100-125
C-130 Hercules	80
F-15 Eagle	10-25
Su-27 Flanker	10-15
Panavia Tornado	8
F-4 Phantom II	6-10
Tank (typical)	6-9
Truck (typical)	6-10
MiG-29 Fulcrum	3-5
Su-35	2
MiG-29K	1-1.5
MiG-35	0.3
F-16A	5
F-18 C/D Hornet	1-3
J-20 Chengdu	1-3

Mirage 2000	1-2
F-16 C (With reduced RCS)	1.2
T-38 Talon	1
B-1B Lancer	0.75-1
JAS-39 Grippen	0.5
Su-57	0.1-0.5
Tomahawk SLCM	0.5
Tomahawk ALCM	0.05
Exocet, Harpoon	0.1
Eurofighter Typhoon	0.5
F-18 E/F Super Hornet	0.1 class
F-16 IN Super Viper	0.1 class
Rafale	0.1 – 0.2
227 mm MLRS	0.018
B-2 Spirit	0.1 or less
Mortar bomb	0.01
U-2	0.01
bird	0.01
F-117A Nighthawk	0.001-0.01 (0.003)
F-35 Lighting II	0.0015-0.005
F-22 Raptor	0.0001-0.0005
Artillery shell	0.0001
insect	0.00001
B-21	0.000001

*Real RCS values are highly classified. The above values, most probably, refer to the frontal aspect (“head on”) RCS of a “clean” aircraft (without external loads), in the X-band (8 − 12 GHz) (**Figure 1-16**).

Principle of RCS Measurement

Measurement of a RCS basically involves illuminating the test target with the radar signal at different viewing angles, collecting radar signal back scattered from the target and then comparing it with radar signal back scattered from a calibrated target. The test target and the calibrated target suitable interface with each other are mounted on a positioning platform enabling different target orientations for the purpose of measurement. The target needs to be placed far enough so that the incident wave is an acceptably plane wave. The test setup basically comprises of suitable instrumentation radar, a positioning system for targets, test and calibrated targets, a low background environment with far field behaviour and a suitable data acquisition and control system.

The five basic methods of reducing RCS are shaping, use of radar energy absorbing materials, passive cancellation, active cancellation and plasma (**Figure 1-17**).

Shaping

The most important factor affecting the RCS is the geometry or the shape of the target, not its size. In order to reduce the RCS, the surfaces and edges should be orientated in such way so as to reflect the radar energy away from an expected radar antenna and not back to it. Considering the flat surfaces (facets) and the acute angles of the F-117, it is understood that it was designed in a way that the expected radar energy would be reflected to irrelevant directions and not back to the emitting radar. The designers tried to avoid any possible surface or edge whose normal vectors would look at a direction where possible enemy radar might be found, especially for the frontal aspect (**Figure 1-18**).

Therefore, in the frame of RCS reduction, all bumps, curves etc. should be avoided. In the same way, any external load (pylons, bombs, missiles, fuel tanks, pods) would considerably augment the total RCS. This is the reason why low observability aircraft carry their armament internally, in special bays. Furthermore, armament bay and landing gear bay doors should close tightly, with no gaps in between. Generally, any irregularity of the surface could incur an RCS increase. Propellers are strictly forbidden, while the first stage engine blades should be carefully hidden inside the intake duct. The whole air intake

construction is critical, when designing a low RCS aircraft.

Other than these contributors, the angle of the incoming radar signals is also very important. This is because, as the normal of a surface to a signal changes, total reflected energy and the RCS also change. For example, an aircraft with a 25 m^2 head on RCS, may have a 400 m^2 broadside RCS. The amplitude values for the pattern are relative basis, so don’t represent a real aircraft. The target is located in a plane where 0 degrees represents the nose on position. To understand RCS value variation of an aircraft, in level flight, against radars at the same altitude but at different angles, the target is rotated in the yaw axis. Such patterns are used to analyze the ability of an aircraft to penetrate air defences.

The RCS of the airframe can be reduced by geometrically controlling the incoming signals’ reflection (directionally) and scattering. The first way to accomplish this is to use flat surfaces and rectilinear surfaces all around the aircraft fuselage, which are oblique to the radar signals. The F-117 Nighthawk is a very good example of this kind of RCS reduction technique with shaping. F-117 Nighthawk uses careful faceting technique to reduce RCS by scattering the incoming signals in nearly every direction (**Figure 1-19**).

Some features of an airframe design present dramatically large RCS values. A flat panel, which is a good reflector, is one of these, since it is normal to the radar beam. If this surface is rotated, this will result in reflecting the incoming beams to other angles and will create a smaller RCS for a monostatic receiver. Bill Sweetman, a former editor for Jane’s, and a well-known Stealth advocate, quotes a stealth designer:

> "A flat panel is the brightest target, and also the dimmest. If the panel is at right angles to an incoming beam, it is a perfect reflecting target. Rotate it along one axis and most of the energy is deflected away from the radar. Rotate it along two axes and the RCS becomes infinitesimal".

Conventional vertical stabilizers are one of these flat reflector panels. Canting them inwards or outwards, with high-angles, can prevent incoming radiation from returning back to the radar and also when a rudder-elevator combination is used, the retro reflector of a dihedral, should be avoided. Here, a retro reflector dihedral is two surfaces that are positioned at 90° from one another and these surfaces reflect the radar wave front back along a vector that is

parallel to but opposite in direction to the angle of incidence. Thus, this double bounce maneuver will result in increasing the RCS.

Rather than leaving them as external parts or hung on pylons, hiding the engine(s) and ordnance inside the fuselage/wings of the aircraft or making them blended components within the whole body or wings will reduce the RCS. Moreover, internal storage gives better aerodynamic performance, as the drag reduces. However, available space inside the body for ordnance is usually limited, which decreases the operational performance of the asset.

Compressor blades are another large signal reflector. Along with increasing the RCS of a target, some identification systems, such as radars using non-cooperative target recognition (NCTR) techniques, or one of the measurement and signature intelligence systems (MASINT) technologies, can be used to collect and process the strong radar returns from the engine compressor movements or periodic rotation of the blades of a turbine to discriminate between enemy and friendly assets. Thus, an aircraft engine (with all possible components) should be kept out of reach of radar signals for low observable designs.

Using wire mesh (as in the F-117 and RPV Q-2C), specially curved air inlet nacelles that prevent the direct reach of RF signals to compressor blades (such as the B-1B) and carefully chosen engine (inlet) locations will also help to reduce RCS. However, placing engines at their most optimum location to reduce RCS raises another important problem, determining the direction of expected RF signals. For example, if a radar threat is expected from below, putting the engine inlets at the top of the wing or airframe would be an effective measure. This is the more likely situation for high altitude bombers, reconnaissance and maritime patrol aircrafts. B-2 and F-117 bomber aircraft are good examples of this kind of design. However, for an air-superiority fighter, estimating the threat direction is a much more complex issue and there is no satisfying solution to this problem. So, the use of serpentine ducts and inlet wire meshes are more effective solutions to conceal the engines from radar signals.

Cockpits and their interior instruments, such as pilot’s helmet, seat, control components and displays, reflect RF signals and increase the RCS, as the canopies and windshields are normally transparent to the radar beams. Some special absorbent (or reflecting) layers and coatings are used on the canopies of the stealth aircrafts to decrease the RCS of the cockpit as well as their unique

external shapes. Along with the stealth aircrafts, some other fighters and EW assets such as F-16 Fighting Falcon and EA-6B Prowler also use such coatings either to reduce RCS or to shield the powerful signal emitted by the jammers from reaching the cockpit and crew. Controlled cockpit canopy shape, with “transparent conductor thin film (vapor-deposited gold or indium tin oxide).” on it, block the incoming radar signals to reach the inner components and diminishes the amount of reflected radar waves back to the radar.

Other RCS reduction methods concerned with shaping include avoiding gaps and holes in the design and using covert gun ports, to hinder discontinuities on the airframe surface. Performing high precision maintenance also helps to obtain and sustain these low RCS levels. In one case, a single screw not tightened as required was discovered to be the reason for an unexpected RCS increase in the F-117 prototype.

The biggest effort in reducing the RCS is given to the forward aspects of the aircraft. However, in this case, greater returns for the other aspects or at least some angles are inevitable. This trade-offs promises some advantage to countermeasures of stealth such as well-designed bi-static radar networks. Secondly, though shaping is the first principle in reducing RCS and must be carefully considered in the design of low observables, long wavelengths are less affected by the shape of the airframe and its details.

The RCS of the airframe can be reduced by geometrically controlling the incoming signals’ reflection (directionally) and scattering. The first way to accomplish this is to use flat surfaces and rectilinear surfaces all around the aircraft fuselage, which are oblique to the radar signals. The F-117 Nighthawk is a very good example of this kind of RCS reduction technique with shaping. F-117 Nighthawk uses careful faceting technique to reduce RCS by scattering the incoming signals in nearly every direction (**Figure 1-20**).

The second reduction method is similar and involves reflecting the incoming signals in a limited number of directions rather than scattering them in all directions. So a monostatic receiver never gets the transmitted signal back, unless the radar signal reflects with two 90 degree angles from a surface, which is improbable when extreme look-down angles are not present. If a bistatic system is considered, its receiver can only get the radiated beam when the spatial geometry is perfect. In this technique, every straight line on the entire airframe should be designed carefully; shape of the aircraft, from main aircraft

components such as wings, vertical and horizontal stabilizers, engine inlets, rudders, to all other moving parts such as rudders, elevators, ailerons, weapon bays, landing gear doors, canopy fasteners, etc., should be aligned in the direction of the few selected spikes (to reflect the incoming signal towards only these specific directions). Using serrated (sawtooth shape) parts on surfaces may also help achieve the desired results.

The third method is modeling the aircraft with a compact, smoothly blended external geometry which has changing curves. These curves do not have regular reflection characteristics and they usually diminish the radar signal’s energy by capturing them inside the curvature. The B-2 Spirit, especially its engine nacelles, was made with this kind of RCS technology. However, this method requires very precise calculations, thus only the latest (after 1980s) low observable aircraft have had the chance to use it in their computer based designs.

As mentioned, the main purpose of shaping is reducing or, ideally, eliminating the major RCS contributors. However, shaping measures for low RCS has some trade-offs, such as poor aerodynamic performance, increased costs more maintenance requirements or less ordnance capacity. Despite these drawbacks, which will be discussed in the following sections, the gains in RCS reduction compensate for the diminished qualities for the purpose of improving aircraft survivability during operations.

Radar absorbing materials (RAM)

The special shaping is the most important low observability method and it is responsible for the main part of RCS reduction. The second technique is the use of special Radar-Absorbent Materials (RAM) which absorb (part of) the received radar energy and convert it to heat, reducing in this way the reflected energy. RAM neither absorb all received radar energy, nor are efficient at all frequency bands. It is considered as a supplementary approach, helping in reducing RCS when shaping techniques cannot be applied, e.g., in leading edges or engine intakes.

This approach has been followed since WWII, where special paints containing carbon (an imperfect conductor) have been used to reduce the radar return of the snorkels of German submarines. Even though carbon is still being used for such purposes, today magnetic absorbers, based on compounds of iron, are preferred for operational systems. The iron ball paint is a common RAM type and has been used in various low observability aircraft.

Modern aircraft are generally made of composites, which consist of two or more different materials that have dissimilar physical, chemical or electromagnetic properties. Generally, composites are not metal and their RF signal reflection properties are very poor, thus non-metallic airframes are considered to not show up on radar. However, the non-reflected RF signals penetrate the non-metallic airframe and this time the reflection occurs from inside which results from the radar images of engines, fuel pumps, electrical wiring and all other components. Coating or painting the surfaces of airframes with special metallic finishing is the preferred way to prevent the penetration of RF signals through composites. On the other hand, composites are still important. Forms of composites, which consist of some poor conductors of electricity, such as carbon products, and insulators, such as epoxy resin, are used in the airframes to cancel the forms of creeping and travelling waves, by resisting electrical and magnetic currents which reradiate.

Though RAM's performance to decrease the RCS has been enhanced by a factor of ten, since the mid-1980s, an expert still indicates "…shape, shape, shape and materials…" as the most important factors to design a stealth aircraft. It is clear that RAM is not an alternative for the airframe design, and it cannot

transform a conventional aircraft into a stealthy one, however for better RCS values, some parts of the asset, especially edge reflections and cavities (such as inlets), should be healed using RAM, where no other solution is likely.

One of the special RAM coatings is made of reinforced carbon- carbon (RCC). For the most part, RAMs, such as RCC, reduce RCS by absorbing (an amount of) the incoming signal and converting RF energy into heat or by destructive interference. With their appropriate dielectric or magnetic properties, different RAMs are used to get desired RCS results over the maximum possible frequency range. RAM technology is based on the idea of establishing desirable impedance which poses good matching and absorbing qualities, so that the RAM can accept and then attenuate the incident wave. Dielectric qualities of RAM can also be explained as naturally occurring, electromagnetic waves of radar bouncing from conductive objects. However, the molecular structure of the glossy materials causes RF energy to expend its energy by producing heat. Then the heat is transferred to the aircraft and dissipated while the residual RF energy loses its effectiveness, basically with help of friction and inertia or molecular oscillations. Finally, this results in less reflection back to the radar receiver.

Together with absorption, another way of RCS reduction, by using RAM, is destructive interference. However, there is an important distinction between the phenomenon of absorption and destructive interference applications. As mentioned above, the absorption process, which covers ohmic loss (based on the motion of free charges in an imperfect conductor), dielectric loss (based on permittivity), and magnetic loss (based on permeability), is possible by transferring the incident RF wave’s energy to the airframe material as it passes through. On the other hand, the destructive interference (also known as “resonant RAM” or “impedance loading”) principal is based on coatings, or the “Salisbury Screen” method, which are used to reduce RCS by cancellation of multiple reflections. This method is considered both a RAM and a passive cancellation method. This study will discuss destructive interference in the passive cancellation technique section.

RAM includes many types of materials. Six RAM examples, low dielectric foam (epoxy); lightweight lossy foam (urethane); thermoplastic foam (polytherimide); sprayable lightweight foam (urethane); thin MAGRAM silicone resin sheet; and resistive card (R-card) made of metalized Kapton. Another example, a ferrite-based paint, which is called “iron ball”, was used on the U-2 and SR-71 to reduce the RCS.

RAM has some limitations. Although the use of RAM is strengthening for low observability, it never gives perfect results and can never be assumed to decrease an aircraft's RCS values to a large extent. It can absorb a portion of the incident energy, with the rest being reflected. Moreover, certain kinds of RAM can give expected results only for certain frequencies and angles of the incident radar wave. Using different kinds of RAM to broaden the RF spectral coverage, along with thicker and heavier amounts, increases the effectiveness. However, the optimum RAM weight and depth should be evaluated while considering the impact of the application of bulky coatings, which may demolish other flight and mission characteristics of the asset. Inconvenient weather conditions, such as rain, may also decrease the performance of most RAM. Furthermore, aircraft shelters should be constructed with special qualities to provide required RAM protection and maintenance. This is the reason that early B-2 planes were not deployed at US bases abroad where these kinds of special shelters were not available.

Because thick and solid RAM coatings or paintings, which are heavy and bulky, are required but not feasible to get desired RCS reduction over wider bandwidths, an alternative method of using such materials at the inner skin of the airframe is preferred. Radar absorbing structures involve building special materials in special ways, such as honeycomb to attenuate radar waves into load-bearing structure.

The honeycomb structures have very important advantages. First of all, their hexagonal passages, which are bonded together, are physically very strong, flexible and light. From a RCS perspective, their depth, which does not cause considerable weight, is used to form many surfaces to reflect, absorb and attenuate the radar signal. One kind of honeycomb is made up of an outer skin of kevlar/epoxy composite, which is transparent to radar, and an inner skin of reflective graphite/ epoxy. The nomex core, between them, has absorbent properties and its increasing density, front to rear of the honeycomb, improves the effectiveness. The small amount of front-face reflection of the incident radar wave is followed by the radar wave to reach the thinly spread absorber on the outer edges of the core where another small part of the energy is absorbed and the remainder is bounced. So, the travelling wave meets more densely loaded core material as it goes on. Each time, some amount of energy is either absorbed or reflected, and finally the outermost layer of the absorber once again attenuates it and the radar wave, which is checked into the structure, never checks out to free space again.

Another RAS form is used on the leading and trailing edges of low observables, such as the wings and fuselage skin strakes of the SR-71 Blackbird. In this method, gradually increasing absorption is applied to trap the energy, similar to the honeycomb structure. However, in this case, the physical shape of the structure is a saw-tooth pattern. The external surface is coated with a high frequency ferrite absorber. The interior begins with a low-absorption layer and is followed by a more absorbent layer, so; while the deepness increases the absorbent properties are also augmented. The “V” shaped geometry causes the radar signal to bounce towards the opposite side, while the material properties of the structure absorb and provide the incoming signal to diminish the energy, so each bounce results in the loss of some amount of the energy.

The state of the art F-22 Raptor, is the U.S. modern stealth fighter. It has many low observable material properties including RAM, RAS, and IR topcoat. RAS is used to minimize scattering from hard edges, while RAM is used to reduce scattering from surface breaks. Moreover, the IR topcoat reduces the IR signature, along with ensuring the radar and infrared signatures are balanced. Early low observable programs made extensive use of RAM and RAS, which resulted in weight and manufacturing problems. However, modern stealth aircraft designers, with the help of analysis and design tools, combined with extensive testing, have minimized the use of RAM on assets, such as F-22, while still maintaining a low signature. So, modern aircraft use less RAM and RAS materials compared to early generations of low observable aircraft which save significant weight and cost.

In any case, the application of RAM is also a trade-off, since any special paint or coating add to cost and weight (reducing performance), while RAM may require special treatment and maintenance. For example, the B-2 Spirit requires air-conditioned hangars and costly maintenance to retain its low observability capabilities. It should be mentioned that the F-35 features a new low observability substance called fiber mat, which according to L.M. officials has been “cured into the composite skin of the aircraft”, implying that it requires no maintenance.

Passive cancellation

Sometimes also mentioned as “impedance loading”, passive cancellation is based on the idea of creating a (passive) echo source, whose amplitude and phase would be adjusted to cancel another echo source (e.g., by drilling a cavity or port of specific dimensions and shape on the object body). This may be

possible for very simple objects; however, it is prohibitively difficult for complex objects like an aircraft, while a small change of the radar parameters or the simple movement of the object-target could lead to the amplification of the radar return. In fact, this approach attracted some interest in the past but now seems not so promising anymore.

Special material used for signal cancellation purposes to reduce RCS fall into two categories: RAM RCS reduction methods (resonant RAM) and passive cancellation. The resonant RAM method was also introduced as destructive interference or impedance loading in RAM applications. Here all these terms and so passive cancellation system refers to "RCS reduction by introducing a secondary scatter to cancel with the reflection of the primary target."

In this method, special coatings, which are also called "resonant absorbers", are chosen to cancel the incoming signals by being reflected two times (sometimes more than two is also possible for wider frequency covering), one from the front and the other from the back of the layer. Theoretically, having a back-face wave that totally travels one half wavelength more than the one that is reflected from the first layer is essential. Having the correct thickness causes the second reflection to have a 180-degree phase difference with the round-trip (first layer) reflection, thus first and second waves will cancel each other. However, this method strictly relies on layer thickness or $1/4^{th}$ of the wavelength matching.

This method is also known as "Salisbury screen". A resistive screen, which is placed in front of the reflective back plate, bounces nearly 50 % of the incident radar beam back to incoming direction, while the other 50% of the radar wave passes through and reflect from that grey plate. When the distance between these two plates are ¼ of radar signal's wavelength, red and purple waves cancels each other. Because such a thickness is only effective for specific frequencies, this cancellation is called as a "narrowband technique." On the other hand, from a RAM application techniques perspective, dielectric and magnetic loss mechanisms are categorized as broadband absorbers, while they can generally be deployed to cover wider frequency bands than passive cancellation coatings.

Passive cancellation was studied enthusiastically in the 1960s; however, its limited use made it unpopular and resulted in the connotation that it was not a useful RCS reduction method. Obviously, it is not practical to design such a treatment to neutralize all of the echo sources while passive cancellation RCS reduction techniques cannot suppress the radar and weapon systems' relatively

wide frequency extent. Moreover, there is also a risk of strengthening the reflected signal with the change of frequency, or viewing aspect.

Active cancellation

Also called “active loading”, active cancellation is based on the same principle as passive cancellation, which is the creation of an appropriate “destructive” echo, which would cancel the real echo of the target to the radar. Therefore, the target should emit electromagnetic energy synchronized with the received radar energy, with proper amplitude and phase in order to minimize the reflected signal. In other words, the target should take into account the direction of arrival of the radar energy, the amplitude, the frequency, the phase, its own RCS characteristics for the specific frequency and direction, and should be adequately intelligent to create the proper waveform, emitting the right pulse at the right time to the right direction. The technical difficulties are obvious, as well as the possibility to convert the target into a “beacon” of radar energy, in case of wrong implementation. This technique has been reported to be applied by the Rafale and has been implicitly confirmed by Dassault, without revealing any details. Another attempt in the category of “active stealth” is the so-called “plasma stealth” technology. There have been reports that the Russians were conducting experiments on this idea. According to available information, this technology employs ionized gas (plasma), which is produced by a special device on-board and injected in front of the aircraft, creating a protective cloud and reducing considerably the aircraft RCS.

Since the revelation of the stealth technology to the public in the early 1970s, the term stealth has been associated with invisible to radar. In fact, radar is only one of several sensors that is considered in the design of a low-observable (LO) platform. Others include infrared (IR), optical (visible), and acoustic (sound) sensors. It is also important that a low-observable target have low emissions. For example, a stealthy platform may be undetectable to an enemy radar but, if a standard high power search radar is operating on the platform, the search radar is likely to be detected by the enemy's electronic support measures (ESM). Stealthy targets are not completely invisible to radar, as is often implied by the popular media. To be undetectable, it is only necessary that a target's RCS be low enough for its echo return to be below the detection threshold of the radar.

Radar cross section reduction has evolved as a countermeasure against radars and, conversely, more sensitive radars have evolved to detect lower RCS targets. A point of diminishing return is quickly reached with regard to RCS reduction,

however. After the strong scattering sources on a complex target are eliminated, the remaining RCS is due primarily to a large number of small scatterers. Treating these scatterers is much more difficult, and it eventually becomes a question of cost. The financial aspect of low observability has caused a re-examination of the "stealth philosophy." In the early days of stealth, heavy emphasis was placed on reducing RCS, even if it came at the expense of other operational and performance parameters. The modem view of low observability is focused more on achieving an optimum balance between whole hosts of performance measures, of which RCS is only one among equals. They include such things as IR and acoustic signatures, cost and maintainability, operational limitations, and the incorporation of electronic warfare (EW) techniques.

While in most cases all efforts are made to minimize the RCS, there are some applications that require enhancement or accentuation of RCS. These include targets such as training aircraft, artificial airborne targets such as pilotless target aircraft and aerial decoys that can be towed behind the attacking airplanes to create the false radar signal and deceive radar operators. Training aircraft need to be continuously tracked and enhancement of RCS makes tracking more reliable. Similarly, pilotless target aircraft used for evaluation of missile systems are also tracked by radars. The radar cross-section of a small pilotless drone may be augmented to give it radar cross-section of a much larger aircraft. Augmentation of RCS achieves reliable tracking. Common methods to enhance the RCS include use of Luneburg lenses, corner reflectors and transponders with amplifiers.

The Luneburg lens is a passive RCS augmentation device. It is used to increase the radar reflectivity of a target without the use of additional energy. Luneburg lens is usually composed of concentric dielectric shells. Radar energy incident on one of the faces of the lens is focused at a point on the rear conductive surface of the lens, which then reflects radar energy back to the source. A corner reflector like a Luneburg lens is also a passive retro-reflector that reflects the incident radar energy back in the direction of the source. Unlike Luneburg lenses and corner reflectors that are passive augmenters of RCS, a transponder is an active augmentation device that works on the principle of capturing a portion of radar.

Plasma

Plasma is a partially ionized and electrically conductive gas by means of the

ability of the positive and negative charges to move somewhat independently. Its free electrons make plasma respond strongly to electromagnetic fields. Thus using plasma, which is sometimes considered an active cancellation technique, has been studied and proposed as a possible method of RCS reduction. The inspiration for this method emerged in the late 1950s after spacecraft with a natural plasma layer over their airframes experienced communication interruption incidents while traveling through the ionosphere. Basically, radar waves (actually all electromagnetic waves of certain frequencies) traveling through this conductive plasma cause electrons to exchange their places, ending up with the electromagnetic waves losing their energy and transforming it to other forms, such as heat. Interaction between plasma and electromagnetic radiation is strongly dependent on the physical properties and parameters of the plasma. The most dominating of these properties are the temperature and the density of the plasma. Another important issue is frequency of the incident radar beam. Radar waves, below a specific frequency, are reflected by plasma layer. Plasma layer’s physical properties have significant effect on this process. Long distance communications with HF signals by means of ionosphere scattering and reflection is a good example of this same phenomena. Thus, RCS reduction plasma devices should also control and dynamically adjust the plasma properties, such as density, temperature and composition, for effective radar absorption results.

Plasma stealth technology has some drawbacks from a low observables perspective. Some of these include, emitting own electromagnetic radiation with a visible glow, existence of a plasma trail of ionized air behind the aircraft before dissipation by the atmosphere, and difficulty in producing a radar-absorbent plasma around an entire aircraft traveling at high speed. However, some Russian scientists have declared achieving a hundredfold RCS reduction with plasma technology and this result (if real) is sufficient enough to focus on this method for further research and success in the stealth world.

Another application of plasma is utilizing this technology to deploy antenna surfaces to generate low observability characteristics. While metal antenna poles are reflective parts, a hollow glass tube filled with low pressure plasma can provide an entirely radar transparent surface when not in use.

Although there are some problems in the operational processes associated with plasma, such as the high energy requirement in long interval applications and the necessity of holes in the plasma fields for aircraft onboard radar

activation, Russian plasma stealth research teams have announced the development of a plasma generator which weighs 100 kg and is thus feasible for a tactical air platform. This critical technology may be available on the Su-27 versions (such as Su-34 and Su-35), MIG-35 fighters and also the MIG 1.44 prototype, according to recent claims by Russian officials.

Acoustic Stealth (Reducing Aural Signature)

Because the probability of detection of radar occurs at greater distances than other signal detection methods, it demands the highest priority in the development of aircraft low observable technology. IR and after that, visual signatures fallow the radar, while sound is the least important of the four aspects of stealth. Practically speaking, acoustic detectors are unable to meet the demands of today's sensor technologies in the aviation world, due to the very low propagation speed of sound waves. However, a comprehensive stealth design includes measures to diminish the ability of acoustic sensors to locate an aircraft. Furthermore, in the future, technological improvements in sensitive aural signature detection systems may minimize low observables' advantages over the focused areas, such as radar, IR and visual signatures, if they are not also concealed by acoustic stealth measures. In the same way, stealth aircraft, which are undetected by other means of tracking or visual systems (including eyesight), can further enhance their advantage by also deploying with features to defeat acoustic detection systems.

Despite the poor qualities to detect targets in free space, using acoustic detection devices in some other mediums can be preferable. It is not the focus of this study, but outlining the importance of acoustic stealth in other application areas may be valuable, in this manner. For example, in submarine warfare, having different requirements, reducing aural signature plays a significant role in the physical medium of sea water. Aircraft acoustic signature reduction focuses on the engines, which produce a significant amount of noise. The slipstream of the aircraft also produces noise, but it is inconsequential when compared to the roaring of the engines. There are several ways to prevent the sound of engines from being detected. Flying at high altitudes reduces the detection risk; however, mission requirements may sometimes compel low-level flight. Cruising around at the speed of sound may be another solution, but this cannot conceal the asset when it flies away from the detection source. Additionally, most aircraft cannot fly more than 10 to 20 minutes at such high speeds and designing an aircraft which can fly for longer periods introduces a number of complexities. For example, the F-22 Raptor can almost fly an entire mission above the speed of

sound using its “supercruise” capability, which does not require afterburner use. However, this capability has many drawbacks, including high engine cost and complex fuselage design. The most promising approach in minimizing aircraft aural signature is making assets quieter by design. In fact, more efficient engines tend to produce less noise. Aircraft engines which inhale a large volume of air but push a small amount, such as high-bypass-ratio turbofans, are quieter than those that inhale a small volume of air but push a large amount, such as low-bypass-ratio engines. Despite this efficiency and acoustic signal reduction advantages, most combat aircraft use low-bypass-ratio engines, which are more suited for applications that require immediate thrust, high velocity and acceleration, and agile maneuverability.

When quietness becomes a bigger concern, high-bypass-ratio turbofans are preferred, even though high performance and speed is reduced. The A-10 Warthog is a good example of this kind of design. Because it is deployed for close air support missions, to friendly ground forces, and its main targets are ground enemy forces, like tanks, armored vehicles and large groups of troops, it needs to fly over these targets several times. A reduced aural signature is crucial in increasing the A-10’s operational success rate due to its requirement to conduct multiple reattacks. Thus, noiseless engines, together with other low observability features, such as IR and visual signature reduction methods, help these aircraft improve their survivability and mission capability. Successful example of acoustic stealth is demonstrated by the Lockheed YO-3A quiet reconnaissance aircraft. This aircraft, which was used by the U.S. Army in the Vietnam War, was deployed for tracking enemy forces that were moving at night, in large groups with equipment, inside dense forests. Conventional reconnaissance or observation aircraft were easily detected by enemy forces from their engine sounds; therefore, several studies focusing on reducing engine noise were commissioned. One of these resulted in the Q-Star prototype, which was developed from X-26 sailplanes, using a liquid cooled engine buried in the rear fuselage for more effective silencing. After several experiments, fourteen Lockheed YO-3A aircraft were produced and used to respond to the requirement for avoiding acoustic detection and fulfilling the mission. These aircraft had a modified light plane engine utilizing a long exhaust pipe. This exhaust pipe was attached to another long muffler fitted on the fuselage side. Moreover, the engine had a large, slow-rotating propeller, which was six bladed, wooden and rubber belt driven. This propeller was later replaced with a three bladed, constant speed counterpart for improving silencing YO-3A with Effective Noise Cancelling Mufflers on the Right Side of the Fuselage. Q-Star with Novel Engine Propeller

Design to Reduce the Noise. The U.S. F-117 Nighthawk and B-2 Spirit, all aspect stealth aircraft, also incorporate design features that reduce engine noise, such as sound-absorbing linings inside their engine intakes and exhaust cowlings. Further, their engine inlets and exhausts are located on top of their wings, they have the ability to fly at relatively high altitudes, and they cruise at subsonic speeds with non-afterburning engines, all of which improve their acoustic signature measurements. Supersonic speeds generate sonic booms which are usually unacceptable for stealth purposes due to the increased risk of detection.

IR signature and STEALTH

All substances with a temperature above absolute zero (0° K, or -273.15° C, or -459.67° F), emit electromagnetic waves. The heat content of a material produces molecular vibrations which cause electron oscillations. These oscillations provide electromagnetic coupling that produces an emission of energy. This emission is called infrared radiation (IR). IR has a wavelength spectrum of 0.7 to 14 micrometers, and the amount of radiation emitted is primarily dependent on the physical temperature of the associated object (proportionally). The emissivity characteristics of an object are related to the material’s molecular structure and the surface conditions of the object. IR energy that comes from another body is either absorbed or reradiated by the object according to its emissivity properties.

As with visible light, IR energy also travels in a straight line at speed of light. Similarly, IR energy is either reflected or absorbed and converted to heat when it hits the surface of an object. These absorption and reflection qualities change with material specifications. For example, polished surfaces reflect more IR energy but also have a much lower emissivity than matte surfaces. IR energy considerations are important to stealth designers, because IR detectors, also known as infrared homing devices, such as passive missile guidance systems, can use IR emissions from a target to track it. Detector systems, especially missile guiding seekers, which detect the radiated infrared signals of their target, are often referred to as "heat-seekers". If unaided by IR countermeasures, aircraft are vulnerable to detection by such systems by means of the strongly radiated energy from their hot bodies. Some precautions to mitigate such detection include, reducing or suppressing an aircraft’s IR signature and adding some noise, deploying decoys or flares, and jamming the sensor by emitting high power signals towards the detector. For an asset designed to remain undetected,

one of the most important measures is reducing or suppressing the aircraft's IR emissions. Thus, sources, surfaces or components which produce and/or conserve heat are of great concern to low observables.

Moreover, the IR detection capability of the new IR Search and Track (IRST) systems and Electro-Optic (EO) systems deployed on the SU-27, Eurofighter Typhoon, and F-35 Lightning II, reveal the importance of IR signature reduction. These EO detectors absorb electromagnetic radiation and output an electrical signal that is useful for tracking and targeting their target. Another major advantage of these systems is that they are passive systems in which a target never knows that there is a threat trying to detect it. Further consideration for IR detection is revealed by the efforts required to increase combat effectiveness of stealth aircraft. When radar detection range is minimized by RCS reduction methods, other signatures such as IR, visual and acoustic become more pronounced, especially for close range engagements.

IR signal reduction is focused on engine exhausts. The back side of an engine is the major source of IR radiation in an aircraft, and when the afterburner is applied, the heat increases significantly, by nearly fifty times, since IR energy emitted from the engines is proportional to the fourth power of absolute temperature. Thus, the second generation stealth F-117 Nighthawk and the third generation strategic stealth bomber B-2 Spirit have non-afterburning engines. On the other hand the fourth generation stealth F-22 Raptor has the ability to cruise at supersonic speeds, but without afterburner. Being dependent to high Mach numbers for operation survivability, the first generation stealth SR-71 Blackbird is also an exception, with its high power afterburner engines.

One method to decrease the IR signature of the engines is to use exhaust masking. This is accomplished by placing the engines on top of the body and the wings. This is the reason the F-117 A and B-2 exhausts cannot be seen from below. Over the rear conical sector of the aircraft, the hottest parts of the tailpipe can be easily detected by IR seekers. While outside of this sector, sensors can only detect the hot parts of the nozzle surface. Another technique to decrease the IR signature is using the aircraft's aft fuselage and vertical surfaces to shield the jet pipes from view over as large a part of this rear sector as possible.

Another method to decrease IR signature is the shaping of exhaust geometry. Exhausts that are shaped flat and wide are effective in this regard.

Integrated Air Defence Systems (IADS)

As we saw in the previous chapter, radar systems have the inherent capability to determine accurate range, azimuth, and/or velocity information on airborne targets. Radar systems can provide this information in nearly all types of weather, day or night, and at distances that far exceed the capabilities of the human eye. Military commanders have taken advantage of these capabilities by employing radar systems to provide air defense for high-value targets. The primary missions of radar systems employed for air defense are attack warning and threat engagement.

Radar systems specifically designed to provide attack warning are called Early Warning (EW) radars. These radars are characterized by high power output, large antennas, and low frequencies. These same characteristics limit the accuracy of the target parameters available from early warning radars. The long-range detection of aircraft and the earliest possible attack warning capabilities of early warning radars provide the first line of defense for the air defense system.

Radar systems designed to provide target engagement information include Ground Control Intercept (GCI) radars, Acquisition Radars (AR), Target Tracking Radars (TTRs), and Airborne Interceptor (AI) radars.

GCI radars are designed to provide sufficiently accurate target aircraft range, azimuth, and altitude information to vector Al assets to intercept and destroy attacking aircraft. To provide this data, early warning radars can be deployed along with specialized height finder radars. This combination of radar systems is commonly referred to as a GCI site. Newer GCI radar systems, employing phased array antennas and Doppler processing, can provide the required 3-dimensional target information. Any radar system, or combination of radar systems, that can determine 3-dimensional target data, and is equipped with the communication equipment to pass this information to AI assets, can act as a GCI site. GCI radar systems can be used to supplement early warning radar systems to provide critical attack warning.

Acquisition radar systems are designed to act as GCI radars for ground based TTRs. Acquisition radar systems generally have shorter range capability than early warning radars and operate at higher frequencies. These radar systems

provide accurate target range and azimuth data to TTRs to facilitate target engagement. Acquisition radars can be a distinct radar system or be incorporated as part of the TTR.

The primary role of TTRs, in support of an air defense system, is to provide continuous and accurate target parameters to a fire control computer. The fire control computer uses this data to guide missiles or aim antiaircraft artillery (AAA) to destroy attacking aircraft. TTRs employ various tracking techniques to continuously update target parameters. TTRs generally employ high frequencies, narrow beam widths, and computer signal processing to enhance the accuracy of target parameters provided to the fire control computer.

Al radar systems are TTRs employed by fighter aircraft to engage and destroy airborne targets. These radar systems are characterized by high frequency, sophisticated computer processing, and accurate target tracking capability. They are designed to allow the Al asset to employ air-to-air missiles and guns/cannons. TTRs and Al radars constitute the highest radar threat associated with an air defense system.

Another growing lethal threat associated with an air defense system is infrared (IR) missiles. IR missile systems can be man-portable, mounted on vehicles, or employed by Al assets. These missile systems guide on the distinctive IR signature of aircraft. The recent proliferation and enhanced performance of IR systems has increased the contribution of these systems to air defense.

All these radar systems can be deployed to provide air defense for a particular country or geographical area. When the employment of these radar systems is integrated by a command and control (C2) structure, this constitutes an IADS. The C2 structure allows the military commander to take advantage of the threat warning provided by early warning radars. Based on this threat warning, the military commander can allocate specific assets (GCI and Al assets, or acquisition radars and TTRs) to engage airborne targets. This allocation decision is based on the capabilities of these systems and the tactical situation. This allocation process enables the military commander to maximize the capabilities of his forces to engage and destroy attacking aircraft (**Figure 1-21**).

Radar systems are the cornerstones of a modern IADS. Radar and IR threat systems operate at frequencies that span most of the electromagnetic spectrum.

Each system has unique capabilities and operating characteristics that enable it to accomplish assigned tasks in support of the IADS. In order to effectively employ offensive air power on the modern battlefield, the systems that support the IADS must be negated. A basic knowledge of how radar and IR systems operate, their capabilities, limitations, and the available countermeasures is the key to defeating these systems.

Former Yugoslavia had the IADS but far from the often described most sophisticated one. It was the old system but functional.

Radar Jamming

Radar jamming is the intentional radiation or re-radiation of radio frequency (RF) signals to interfere with the operation of radar by saturating its receiver with false targets or false target information. Radar jamming is one principal component of electronic combat (EC). Specifically, it is the electronic attack (EA) component of electronic warfare (EW). Radar jamming is designed to counter the radar systems that play a vital role in support of an enemy integrated air defense system (lADS). The primary purpose of radar jamming is to create confusion and deny critical information to negate the effectiveness of enemy radar systems.

This chapter will introduce the two types of radar jamming, the three radar jamming employment options, and discuss the fundamental principles that determine the effectiveness of radar jamming.

There are two types of radar jamming: noise and deception.

Noise jamming is produced by modulating a RF carrier wave with noise, or random amplitude changes, and transmitting that wave at the victim's radar frequency. It relies on high power levels to saturate the radar receiver and deny range and, occasionally, azimuth and elevation information to the victim radar. Noise jamming takes advantage of the extreme sensitivity of the radar receiver and the transmission pattern of the radar antenna to deny critical information to the victim radar.

Deception jamming uses complex receiving and transmitting circuits to process and retransmit jamming pulses that appear as a real target to the victim radar. A deception jammer receives the signal from the victim radar and alters the signal to provide false range, azimuth, or velocity information. The altered

signal is then retransmitted. The victim radar processes this signal, which disrupts the victim radar and confuses the radar operator. To be effective, deception jamming must match not only the victim radar's operating frequency, but all the other operating characteristics, including pulse repetition frequency (PRF), pulse repetition interval (PRI), pulse width, and scan rate.

Both noise and deception jamming effectiveness are heavily dependent on another component of EW, specifically, electronic warfare support (ES). ES assets, either airborne or ground-based, provide the threat system specific radar parametric data and update this critical information based on observed threat system operations. This data provides the foundation for developing noise and deception jamming techniques. Intelligence and engineering assessment of this data are used to identify specific threat system weaknesses that can be exploited with the optimum noise, deception, or combination of jamming techniques. This information is then programmed into jamming systems to counter specific threats.

There are currently two primary employment options for both noise and deception jamming techniques. These options are:

1. support jamming, and
2. self-protection jamming.

Support jamming can be broken down further into standoff jamming (SOJ), and escort jamming. To counter early warning, ground control intercept (GCI), and acquisition radars associated with an enemy lADS, noise and deception jamming techniques are employed by specialized support jamming aircraft. The goal of support jamming is to create confusion and delays within the command and control structure of the IADS. Deny, delay or degrade the enemy's ability to engage friendly forces. Support jamming operations can be focused against a national level IADS through the use of a stand-off jamming (SOJ) profile or against a target area threat array using an escort jamming profile.

From an orbit area outside the surface-to-air missile (SAM) engagement zone, SOJ aircraft employ specialized jamming techniques to deny the enemy information about the attack package. SOJ aircraft employ specialized noise jamming techniques to generate jamming strobes on the victim radar display. This effectively denies range and azimuth information on aircraft ingressing and egressing the area covered by the noise jamming strobes. Intensity of the strobes is based on the power in the jamming. The area covered is based on the amount

of jamming that can be injected into the main beam and sidelobes of the victim radar. The effectiveness of SOJ noise jamming is determined by the power the jammer can generate relative to the power the victim radar can generate. This is called the jamming-to-signal (J/S) ratio.

SOJ aircraft can also employ a deception technique to generate false targets to confuse the radar operator and mask the presence of real targets In this specialized technique, the deception jammer must tune to the frequency, PRF, and scan rate of the victim radar. The jammer then transmits multiple jamming pulses that the victim radar receiver processes like real target returns. With enough power, the deception jammer can generate multiple false azimuth targets by injecting jamming pulses into the sidelobes of the victim radar. False moving targets and false range targets are generated by varying the time delay of the jamming pulses based on the PRF and scan rate of the victim radar.

Escort jamming is a specific tactic used by the EA-6B Prowler. The EA-6B is employed as an integral part of the attack package and is normally positioned behind and above the attack package. Using noise jamming, the EA-6B attempts to deny range and azimuth information to the victim radar by injecting high power signals into the main radar beam and sidelobes. To be effective, the EA-6B must be properly positioned in relation to the ingressing or egressing attack package (**Figure 1-22**).

Self-protection radar jamming targets the radar systems that support jamming cannot negate. Self-protection jamming systems are part of a self-protection suite that includes a self-protection jamming pod, a chaff/flare dispenser, and on some aircraft, a towed decoy system. The overall purpose of these systems is individual aircraft survivability. These systems are designed to counter the individual SAM, AAA, and Al assets associated with the enemy lADS. They employ deception jamming techniques against the target tracking radars (TTRs) associated with these threats. They are designed to break the radar track or generate sufficient tracking errors to cause the missile or bullet to miss the aircraft.

Self-protection radar jamming systems usually employ deception jamming techniques based on several factors. First, effective deception jamming techniques generally require less power than noise jamming techniques. Second, less power means less weight and space, which are very important considerations for modern tactical aircraft. Finally, deception jammers can be

designed to jam multiple threats, which is a critical requirement for operations in a dense threat environment.

Despite the advantages of deception jamming techniques for self-protection jamming, there are some limitations that must be considered. First, deception jammers are complex electronic systems that must receive victim radar's signal, memorize all its characteristics, modify the signal, and retransmit this modified signal at a high-power level. Second, to be effective, deception jammers must be programmed with all the signal parameters (frequency, PRF, PRI, pulse width, scan rate, etc.) of the victim radar. Finally, because many deception techniques can be effective against specific threats, selecting optimum techniques to employ against these threats must be based on identified threat

A radar noise jamming system is designed to generate a disturbance in a radar receiver to delay or deny target detection. Since thermal noise is always present in the radar receiver, noise jamming attempts to mask the presence of targets by substantially adding to this noise level. Radar noise jamming can be employed by support jamming assets or as a self-protection jamming technique. Radar noise jamming usually employs high-power jamming signals tuned to the frequency of the victim radar.

Noise jamming is produced by modulating an RF carrier wave with random amplitude or frequency changes, called noise, and retransmitting that wave at the victim radar's frequency. Since noise from numerous sources is always present and displayed on a radar scope, noise jamming adds to the problem of target detection. Reflected radar pulses from target aircraft are extremely weak. To detect these pulses, a radar receiver must be very sensitive and be able to amplify the weak target returns. Noise jamming takes advantage of this radar characteristic to delay or deny target detection.

Deception jamming systems are designed to inject false information into a victim radar to deny critical information on target azimuth, range, velocity, or a combination of these parameters. To be effective, a deception jammer receives the victim radar signal, modifies this signal, and retransmits this altered signal back to the victim radar. Because these systems retransmit, or repeat, a replica of the victim's radar signal, deception jammers are known as repeater jammers. The retransmitted signal must match all victim radar signal characteristics including frequency, pulse repetition frequency (PRF), pulse repetition interval (PRI), pulse width, and scan rate. However, the deception jammer does not have to

replicate the power of the victim radar system.

A deception jammer requires significantly less power than a noise jamming system. The deception jammer gains this advantage by using a waveform that is identical to the waveform the radar's receiver is specifically designed to process. Therefore, the deception jammer can match its operating cycle to the operating cycle of the victim radar instead of using the 100% duty cycle required of a noise jammer. To be effective, a deception jammer's power requirements are dictated by the average power of a radar rather than the peak power required for a noise jammer. In addition, since the jammer waveform looks identical to the radar's waveform, it is processed like a real return. The jamming signal is amplified by the victim radar receiver, which increases its effectiveness. The reduced power required for effective deception jamming is particularly significant when designing and building self-protection jamming systems for tactical aircraft that penetrate a dense threat environment. Deception jamming systems can be smaller, lighter, and can jam more than one threat simultaneously. These characteristics give deception jammers a great advantage over noise jamming systems.

Although deception jammers require less power, they are much more complex than noise jammers. Memory is the most critical element of any deception jammer. The memory element must store the signal characteristics of the victim radar and pass these parameters to the control circuitry for processing. This must be done almost instantaneously for every signal that will be jammed. Any delay in the memory loop diminishes the effectiveness of the deception technique. Using digital RF memory (DRFM) reduces the time delay and enhances deception jammer effectiveness. Deception jamming employed in a self-protection role is designed to counter lethal radar systems. To be effective, deception jamming systems must be programmed with detailed and exact signal parameters for each lethal threat.

The requirement for exact signal parameters increases the burden on electronic warfare support (ES) systems to provide and update threat information on operating frequency, PRF, PRI, power pulse width, scan rate, and other unique signal characteristics. Electronic intelligence (ELlNT) architecture is required to collect, update, and provide changes to deception jamming systems. In addition, intelligence and engineering information on exactly how a specific threat system acquires, tracks and engages a target is essential in identifying system weaknesses. Once a weakness has been identified, an effective deception

jamming technique can be developed and programmed into a deception jammer. For example, if a particular radar system relies primarily on Doppler tracking, a Doppler deception technique will greatly reduce its effectiveness. Threat system exploitation is the best source of detailed information on threat system capabilities and vulnerabilities. Effective deception jamming requires much more intelligence support than does noise jamming.

Most self-protection jamming techniques employ some form of deception against a target tracking radar (TTR). The purpose of a TTR is to continuously update target range, azimuth, and velocity. Target parameters are fed to a fire control computer that computes a future impact point for a weapon based on these parameters and the characteristics of the weapon being employed. The fire control computer is constantly updating this predicted impact point based on changes in target parameters. Deception jamming is designed to take advantage of any weaknesses in either target tracking or impact point calculation to maximize the miss distance of the weapon or to prevent automatic tracking.

Decoys

A decoy is a device designed to look to an enemy radar more like an aircraft than the actual aircraft itself. Decoys do three primary missions: they saturate the enemy's integrated air defense system (IADS), coerce the enemy into exposing his forces prematurely, and defeat tracking by enemy radar.

Saturation decoy

A saturation decoy is usually an expendable vehicle designed to emulate a penetrating aircraft. Its mission is to deceive and saturate an enemy's IADS. Employing multiple saturation decoys can force an IADS to devote critical resources to engage these false targets. This depletes enemy assets available to engage penetrating aircraft. In addition, ground or air launched saturation decoys can be used to stimulate the IADS, to collect intelligence data, or to initiate attacks by suppression of enemy air defense (SEAD) assets. The three main characteristics of saturation decoys are their electronic signature, their flight program, and their mission type.

Saturation decoys must present an electronic signature, or radar return, that is indistinguishable from the aircraft they are protecting. Decoys can do this by either passive or active measures or use a combination of both. A passive decoy is essentially a flying radar reflector. The size, shape, and materials used in the

decoy are optimized to ensure that the proper amount of radar energy is returned to the enemy radars. Active decoys employ radar repeater systems to receive the enemy radar signal, amplify it and send back a radar return of the proper size to confuse the enemy. Reflecting or transmitting the proper size radar return is critical for both passive and active decoys. A return that is too large or too small will allow the enemy radar operator to differentiate between decoys and aircraft, causing the decoys to be ignored.

To continue deceiving an enemy IADS, a decoy must do more than provide the proper-sized radar return. Possessing flight characteristics similar to the aircraft it is protecting increases the probability that the decoy will effectively deceive an IADS for a sustained period of time. Modern decoys can either be powered with rockets, miniature engines, or simply glide for very long distances based upon the altitude and airspeed of the jet that releases them. Additionally, their flight paths can be preprogrammed into an onboard autopilot, allowing the decoy to fly an independent ground track, thus increasing their appearance as attack aircraft worth tracking. Saturation decoys carry out two of the three decoy missions. Launched in significant numbers, they can saturate or overburden an IADS. Meanwhile, their realistic electronic image and pre- programmed flight paths entice the enemy to turn on radars and show his forces.

An extremely successful example of using decoys to stimulate the IADS was carried out in the Bekaa Valley in 1982. The Israelis opened the conflict by launching saturation decoys to successfully simulate an attack. While the Syrians reloaded, Israeli fighters attacked, and destroying 17 of 19 Syrian SA-6s in the beginning of the battle. With the ground threat neutralized, the Israeli Air Force went on to destroy 85 Syrian fighters in the pure air-to-air conflict that resulted (as per western media).

Towed decoy

A towed decoy is a small jammer that is physically attached to the aircraft. Unlike the saturation decoys that work against the IADS, the towed decoys are for individual aircraft survival. Towed decoys are designed to defeat enemy missiles in the final stages of an engagement; therefore, towed decoys, as well as other expendables, are known as endgame countermeasures. While towed decoys are primarily designed to provide sufficient miss distance between an attacking semi-active radar missile and the protected aircraft, they may also be effective against pulse Doppler radars and monopulse radars (**Figure 1-23**).

To be effective, the towed decoy must turn on within the threat radar's resolution cell after the radar is tracking the protected target. To successfully decoy the missile, the towed decoy must return radar signals with sufficient power to simulate a radar cross section (RCS) significantly larger than that of the protected target.

Expendable active decoys

Expendable active decoys are designed to lure the tracking gates of an enemy's radar away from the aircraft. They are endgame countermeasures like towed decoys, but they differ in that expendable decoys free-fall or glide to the ground as opposed to being towed behind the aircraft.

Expendable decoys are small, active jamming systems designed to be expended by existing aircraft chaff and flare dispensers, such as the AN/ALE-40 or the AN/ALE-47. Expendable decoys can employ noise or deception jamming with noise jamming being the most common. Deception jamming techniques can be employed to enhance effectiveness against pulse Doppler radars. There are two challenges associated with expendable jammers: the amount of the time the jammer is effective and the packaging.

Expendable decoys are designed to provide protection for the dispensing aircraft for a specific period. The dispensing altitude and rate of fall determine this period of effective coverage. Expendable decoys can employ small parachutes of aerodynamic design to slow the rate of fall and increase the time of effective coverage.

Chaffs

Chaff was first used during World War II when the Royal Air Force, under the code name “WINDOW,” dropped bales of metallic foil during a night bombing raid in July 1943. The bales of foil were thrown from each bomber as it approached the target. The disruption of German AAA fire control and ground control intercept (GCI) radars rendered these systems almost totally ineffective. Based on this early success, chaff employment became a standard bomber tactic for the rest of the war.

Even today, chaff is one of the most widely used and effective expendable electronic attack (EA) devices. The most important chaff characteristics are radar cross section (RCS), frequency coverage, bloom rate, Doppler content, polarization, and persistence. It is a form of volumetric radar clutter consisting of

multiple metalized radar reflectors designed to interfere with and confuse radar operation. It is dispensed into the atmosphere to deny radar acquisition, generate false targets, and to deny or disrupt radar tracking. Chaff is designed to be dispensed from an aircraft and function for a limited period.

Chaff screening and self-protection are the two basic chaff employment tactics. Chaff screening tactics, including area saturation and chaff corridor employment, are designed to confuse and deny acquisition information to the early warning, GCI, and acquisition radars supporting surface-to-air missile (SAM) systems. Self-protection tactics are designed to counter acquisition and target tracking radars (TTRs). When used with jamming and maneuvers, chaff can cause TTRs to break lock or generate survivable miss distances if a SAM is fired at the aircraft.

Flares

Since their introduction in the 1950s, infrared (IR) missiles have been an increasing threat from both ground-based and airborne systems. The range, reliability, and effectiveness of IR missiles have been continuously improved by advanced detector materials and computer technology. Since IR missiles are passive, they are relatively simple and inexpensive to produce. These characteristics have contributed to the proliferation of IR missiles in the combat arena. Nearly every aircraft flying in either the air-to-air or air-to-surface role now carries an all-aspect IR missile. Additionally, every infantry unit down to the platoon level is equipped with shoulder-fired IR missiles.

Flares are the primary countermeasure used to defeat the IR missile. Advanced IR missiles use different techniques to overcome the use of self-protection flares. There are two important characteristics of infrared (IR) missiles that influence the effectiveness of self-protection flares. The first is the ability of the IR missile seeker to discriminate between the IR signature of the aircraft and the IR signature of background interference, especially clouds. The second is the flare rejection capability built into the missile seeker and the missile guidance section.

The purpose of employing a self-protection flare cartridge is to decoy the seeker head of an IR missile. This is accomplished by presenting the IR missile with a second heat source with an IR signature that exceeds the aircraft signature. The flare or IR source must appear in the field of view of the IR missile at the same time as the aircraft. As the flare separates from the aircraft,

the IR missile seeker tracks the most intense IR signature, which ideally is the flare, and is decoyed away from the aircraft.

Self-protection flares were developed to counter threat systems operating in the IR spectrum. Self-protection chaff and flare dispensers, such as the ALE-40, ALE-45, or the ALE-47, are designed to allow the pilot to dispense flare cartridges when engaged by an IR threat. These flare cartridges are pyrotechnic and pyrophoric devices designed to produce an IR source that is more attractive than the IR signature of the aircraft. To decoy an IR missile seeker, the flare must create a heat source more attractive than the aircraft, within the missile field of view. The most important flare characteristics that determine the ability of a flare to decoy an IR missile are IR wavelength matching, flare rise time, and flare burn time.

Through the years advances in seeker technology have resulted in significant changes to IR missile engagement tactics. This section will discuss spinning reticle, conical scan, cooled, and imaging IR seekers. First generation IR missiles, like the SA-7, use a spinning reticle as the means to track the target. Due to their relatively low cost and ease of use, IR missiles of the first generation can still be encountered. The spinning reticle is inserted in the seeker just before the IR radiation reaches the detector. The reticle is a thin plate of optical material which has a transparent and opaque pattern on it. As the reticle is rotated, the IR energy is chopped at a rate determined by the reticle pattern. This system produces error signals when the target is not exactly centered in the field of view. If the target is located in the upper half of the pattern, the IR intensity on the detector is constant as the reticle rotates. As the pie-shaped half of the disc rotates over the target, the IR energy is pulsed and the amplitude of the pulses is an indication of relative elevation angle. When the target moves to the right or left, the pulsing starts and stops at different times, indicating target azimuth. Center spun spin-scan seekers, also called center null reticles, are relatively insensitive when the target is in the center of the seeker scan where there is no tracking error. This is because the point target tends to bleed energy into all the spokes at once, eliminating the pulsed signal output of the detector. Once the target falls off the center of the reticle, the seeker generates an error signal that initiates guidance commands to re-center the target. This is the reason early IR missiles flew an undulating path toward the target.

A significant improvement to IR seekers resulted from the cooling of the detector with an inert gas such as argon. Older IR missiles, using uncooled lead-

sulfide detectors, have a peak sensitivity in the 2 micron region. This limits these missiles, the SA-7 for example, to stern attacks because the missiles can only discriminate the IR signature of the engine turbine from background IR energy. By cooling the detector with an inert gas, like argon, the detectors of newer IR missiles can track longer wavelength IR radiation associated with airframe friction. Using newer detector materials like indium antimonide (InSb), require cooling to have increased target detection range and all-aspect tracking capability.

Imaging IR is the most recent advancement in IR seeker technology. The technology for these seekers is similar to that found in the AGM-65 Maverick missile. Imaging IR seekers are harder to decoy with flares than older seekers, and they are resistant to pulsed light jamming. Imaging detection involves creating an IR picture of the scene in one of two ways, scanning or staring. A scanning system uses one detector (or a mix of detectors and mirrors) which moves relative to the scene until the entire scene is scanned. This is an easy system to fabricate, but it can be noisy because the detector can't stay very long at each position, and it does not have a lot of time to measure the signal. A staring system uses many detectors, each of which detects a small portion of the scene. Each detector can “dwell” on its part of the scene for the entire frame time. However, such systems, also called focal plane arrays, are difficult to fabricate in a way such that each detector has the same sensitivity. One of the prime advantages with using imaging IR seekers is that they can be programmed to track a particular IR shape or scene, significantly reducing the effectiveness of decoy flares.

Flares are the primary countermeasure used to defeat the IR missile. Advanced IR missiles use different techniques to overcome the use of self-protection flares. There are two important characteristics of infrared (IR) missiles that influence the effectiveness of self-protection flares. The first is the ability of the IR missile seeker to discriminate between the IR signature of the aircraft and the IR signature of background interference, especially clouds. The second is the flare rejection capability built into the missile seeker and the missile guidance section.

Radar Warning Receiver (RWR)

Radar surveillance and radar-directed weapons represent the biggest threat to aircraft survival on the modern battlefield. The first step in countering these threat systems is to provide the pilot or crew with timely information on the signal environment. The radar warning receiver (RWR) is designed to provide this vital information to the pilot. The RWR system is an example of an electronic warfare support (ES) system. The primary purpose of an RWR system is to provide a depiction of the electronic order of battle (EOB) that can have an immediate impact on aircraft survival. Though the RWR system is complex, the basic operations of the various components are straightforward. A step above RWR systems is threat geolocation. While an RWR provides the EOB for a single aircraft, threat geolocation systems can provide accurate threat location data for numerous aircraft over an entire region. Threat location data is used for aircraft threat avoidance and, more common today, the pre-emptive attacking of enemy radar sites.

RWRs are designed to provide accurate threat positioning information when the aircraft is flying straight and level. Most RWRs will also provide accurate threat positioning information when the aircraft is maneuvering up to certain limits of bank angle and turn rate. If aircraft maneuvering exceeds these limits, RWR threat positioning data becomes unreliable. The two RWR limitations associated with aggressive maneuvering are inaccurate threat azimuth and multiple threat symbols.

The physical location of the RWR antennas on the aircraft can affect its ability to detect a radar signal. Antennas are arranged to cover a predetermined area of horizontal and vertical space around the aircraft. The antennas and their patterns play an essential part in displaying the spatial relationship of a threat radar to the aircraft. The antenna patterns are the areas, or “footprints,” that the antennas are specifically designed to cover. These footprints are directly affected by the relative position of the antennas to the threat systems. This is because the signal processor measures and compares signal strength from all the aircraft antennas to compute threat signal location relative to the aircraft. This relative location is then presented on the RWR scope display. Aircraft movement and maneuvering shifts these relative positions during flight and can distort the true threat position on the RWR scope. Precise position determination is not possible

with most current RWRs.

The sensitivity of an RWR antenna directly affects its ability to detect a radar signal. The more sensitive the antenna, the further it can detect a signal. The sensitivity of a system and its ability to intercept a radar signal is usually expressed in decibels relative to milliwatts or dBm units. A 10 dBm change in sensitivity can result in a 25 nm range difference in target detection. In general, sensitivity levels of -50 to -60 dBms are required to detect signals at long ranges.

The signal processor is the heart of the radar warning receiver. The signal processor is also known as the digital processor or analysis processor in different RWR systems. Its primary functions are to process numerous complex radar signals and identify, among the thousands of similar signals, those generated by lethal threat systems. The signal processor accomplishes this task continuously over the duration of the mission and displays the identified threat system to the aircrew almost instantly.

The signal processor classifies each received signal and corresponding track file by its unique radar signal characteristics. Identifying characteristics used by a signal processor can include radio frequency, pulse width, pulse repetition frequency, EP techniques, and more. Characteristics of one signal may be identical to characteristics from different signals, while certain other characteristics can be as unique as a human fingerprint. The signal processor uses these primary characteristics to identify specific signals. When the primary characteristics of two or more signals are similar, the signal processor uses additional signal characteristics to resolve any confusion between two or more signals.

The signal characteristics in each track file are filled with processed data, and are constantly updated based on the time of arrival and location of the received signals. In addition, the track files are constantly compared to the EID table installed in the signal processor's computer memory. The EID table is a predefined table of radar characteristics associated with known radar systems. It is created from information gathered from electronic warfare support (ES) assets and intelligence sources. This table can be changed and updated as necessary to reflect the most current radar characteristics available for the anticipated threats in the planned theater of conflict. Each RWR system has unique procedures to reprogram the signal processor and update the EID tables. Emergency reprogramming actions, such as would be taken if a new threat appears that is

not part of the current EID, are called a Pacer Ware.

The signal processor continually compares signal characteristics in the track files with the data in the EID tables. Once the signal processor has determined that enough of the signal characteristics match the information in the EID tables, it generates and positions a video symbol on the RWR scope. The video symbol represents a specific threat, and each threat system has its own unique symbol. In addition, an audio tone is generated to alert the pilot. The signal processor also generates symbols and audio associated with specific threat system actions, including search, track, and missile launch. The position of the threat symbol on the RWR scope always represents the relative position of the threat in relation to the aircraft which is the center of the RWR scope. The signal processor compares the received signal strength in the different antennas to determine the proper location of the threat symbol. In addition to generating threat symbols for each identified threat, the signal processor also generates threat audio. Threat audio first alerts the aircrew to the detection of a threat system. This RWR audio is generally referred to as “new guy” alert audio. The signal processor can also present constant audio from a selected threat.

Electronic Warfare (EW)

This will discussed some of the most widely employed Electronic Protection (EP) techniques designed to counter radar jamming. The capabilities of the individual radar operator will not be discussed in this heading. However, the radar operator is as important as the EP techniques designed for the radar system. How the missile system operators work is elaborated in Chapter 8. Many of the most effective EP techniques are designed to ease operator interpretation of the radar display. In the chess game of Electronic Warfare (EW), the capabilities of individual radar operators can be as important as the sophisticated EP techniques in determining the final outcome.

Electronic warfare is defined as military action involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or to attack the enemy. Nearly every military action, from command and control of an entire integrated air defense system (IADS) to precision guidance of an individual weapon, depends on effective use of the electromagnetic spectrum. Radar systems have become a vital element of nearly every military operation. Since these systems operate across the entire electromagnetic spectrum, much of the EW effort is concerned with countering radar systems. All of the jamming techniques discussed in the previous headings are specifically designed to counter radar systems. These actions are classified as electronic attack (EA), which is a part of EW (**Figure 1-24**).

Electronic warfare is somewhat like a chess game - a series of moves and countermoves within the electromagnetic spectrum. As one side develop jamming techniques to counter radar systems, the others develop counter-countermeasures to negate the effectiveness of these techniques. In response, the one develop newer techniques and their adversaries respond with new modifications to their radar systems. This series of moves and countermoves can continue for decades. The development and application of radar counter-countermeasures are classified as electronic protection, also a part of EW.

The continuing battle to control the electromagnetic spectrum for unrestricted radar employment has resulted in over 150 radar EP techniques. These techniques are designed to negate the effectiveness of electronic jamming and chaff on radar systems. These radar EP techniques can be incorporated into

the design of a radar system or added to an existing radar system in response to a jamming technique. It is beyond the scope of this text to discuss all the radar EP techniques in use today. This chapter will discuss the most common EP techniques. They have been organized by function of the technique within the radar. These functions include: radar receiver protection, jamming avoidance, jamming signal exploitation, overpowering the jamming signal, pulse duration discrimination, angle discrimination, bandwidth discrimination, Doppler discrimination, and time discrimination.

The following are some of the most common radar counter-countermeasures designed to prevent receiver overload or saturation.

- Sensitivity time control (STC) is used to counter close-in chaff or close-in clutter.
- Automatic gain control (AGC) is used to counter chaff, clutter, and most types of transmitted jamming. AGC senses the signal level of a receiver's output and develops a back-bias, producing a constant output level.
- Fast automatic gain control (FAGC) is also employed against chaff, clutter, and most types of transmitted jamming. FAGC works by sensing the signal level of receiver output and develops a back-bias, tending to hold output constant. Response time is within milliseconds, permitting fast response and recovery as the antenna traverses the jammer's bearing.
- Instantaneous automatic gain control (IAGC) is another technique to counter chaff, clutter, and most types of transmitted jamming. IAGC senses the signal level of each echo or jamming pulse and develops a back-bias that holds the stage output constant.
- Automatic noise leveling (ANL) counters noise jamming and modulated or unmodulated constant wave jamming. ANL samples receiver noise content at the end of each PRF and sets the gain accordingly for the next pulse interval.
- The logarithmic receiver (LOG) counters most types of transmitted jamming by amplifying and demodulating large dynamic-range signals in logarithmic amplifiers. This produces “amplitude compression” of the strong signals.
- The logarithmic receiver with fast time constant (LOG-FTC) counters narrowband jamming, chaff, and clutter. This technique amplifies and demodulates large dynamic-range signals in logarithmic

amplifiers, producing “amplitude compression” of the strong signals.

- Dicke-fix (DF) counters wideband and fast-swept jamming and is similar in employment to wideband limiting (WBL). DF amplifies without ringing, clips down all pulses to a common level, then amplifies the narrowband echo signal more than the wideband jamming.
- WBL is used to counter wideband jamming and fast-swept jamming. WBL amplifies without ringing, clips down all pulses to a common level, then amplifies the narrowband echo signal more than the wideband jamming.
- Adaptive video processing (AVP) counters chaff corridors, weather, sea clutter, and most types of transmitted jamming.

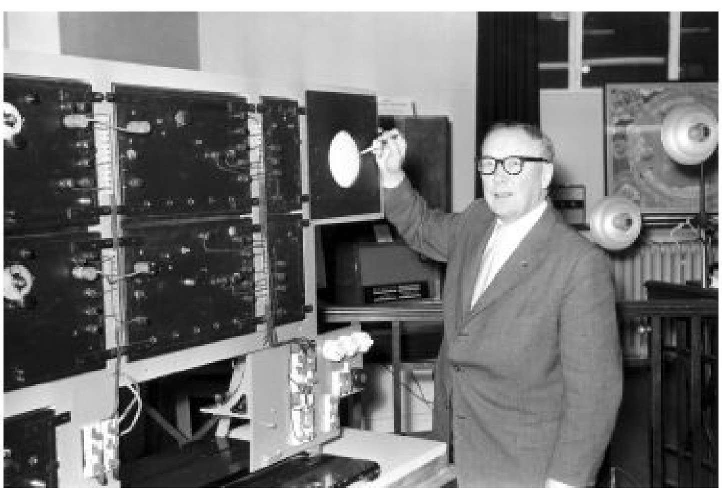


Figure 1-1: Sir Robert Watson-Watt
(Source:sciencemuseum.org)

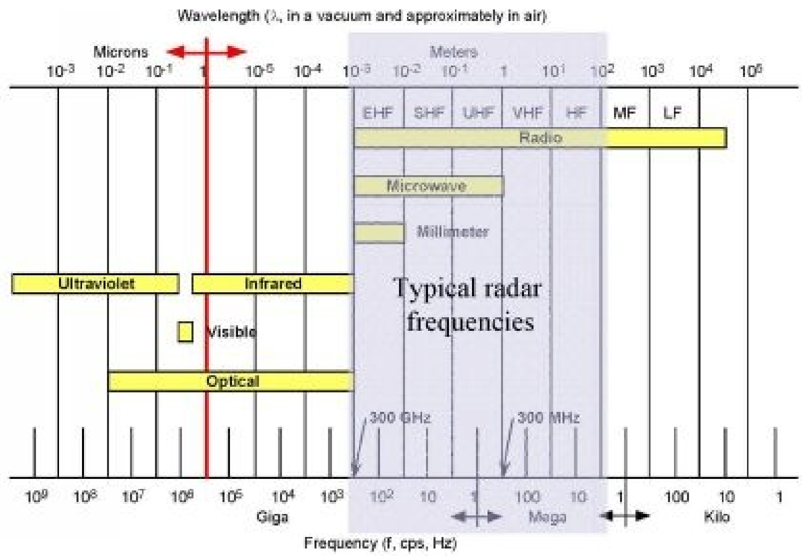


Figure 1-2: Radar frequencies
(Source: Naval Postgraduate School)

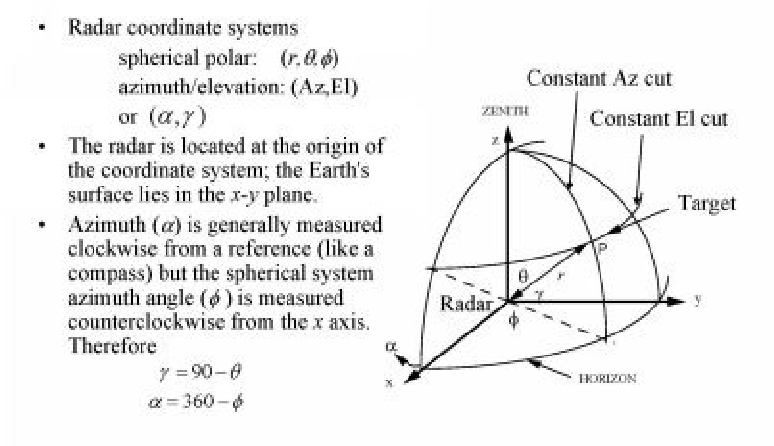


Figure 1-3: Radar coordinate system
(Source: Naval Postgraduate School)

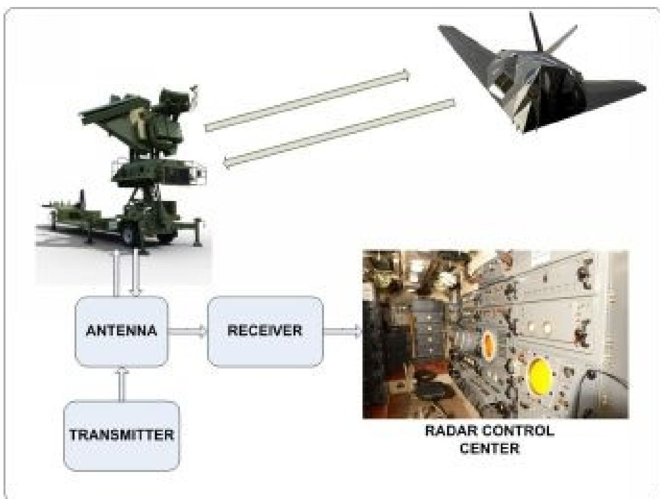


Figure 1-4: Radar system - basic components

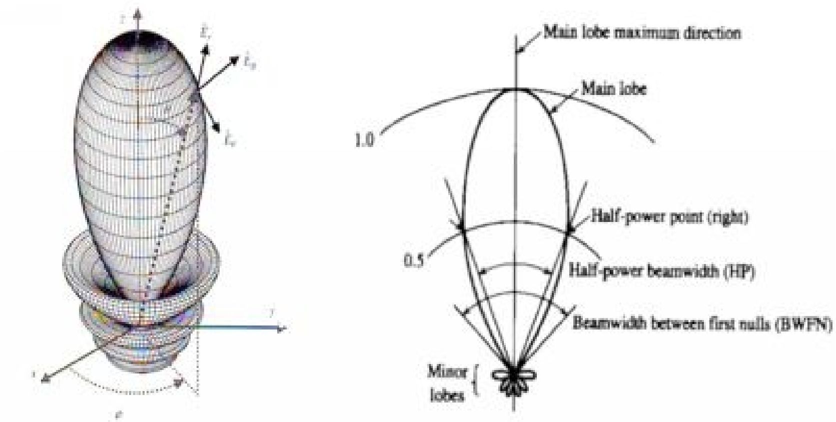


Figure 1-5: Most radar energy is transmitted and received via a main lobe aligned with the antenna's boresight, but smaller amounts enter through sidelobes that point in almost all directions.

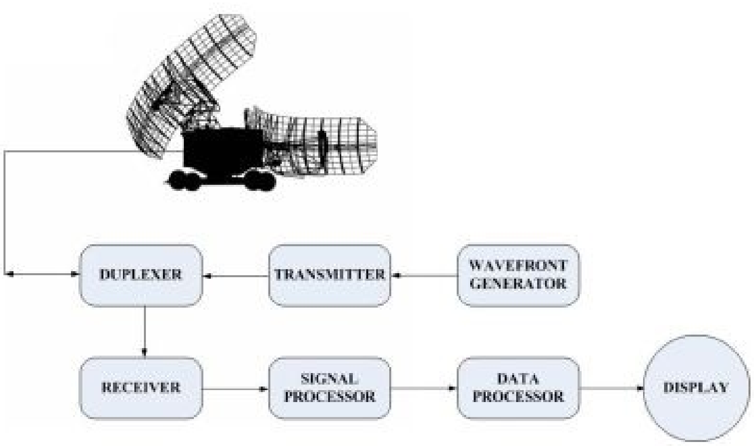


Figure 1-6: Radar system block diagram

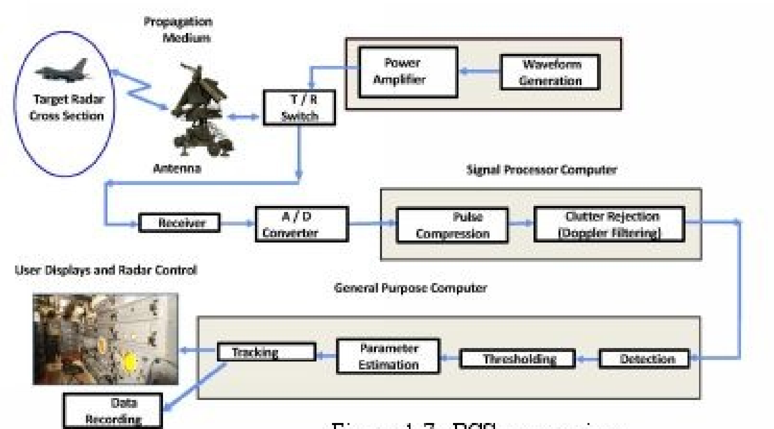


Figure 1-7: RCS processing

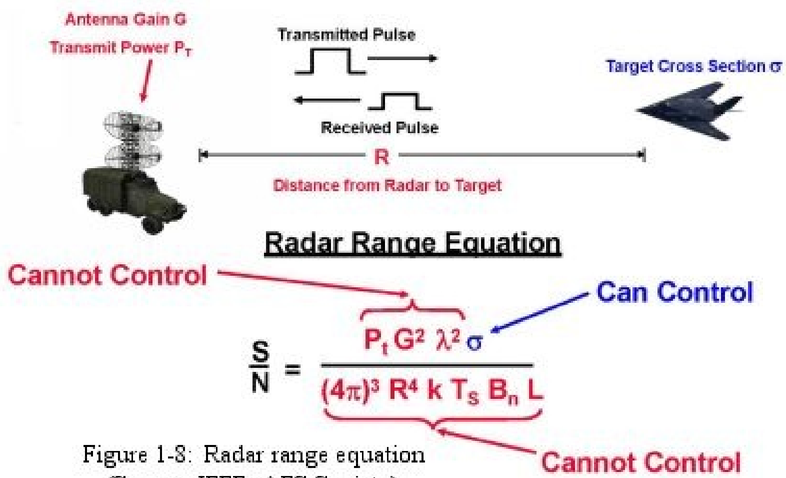


Figure 1-8: Radar range equation
(Source: IEEE AES Society)

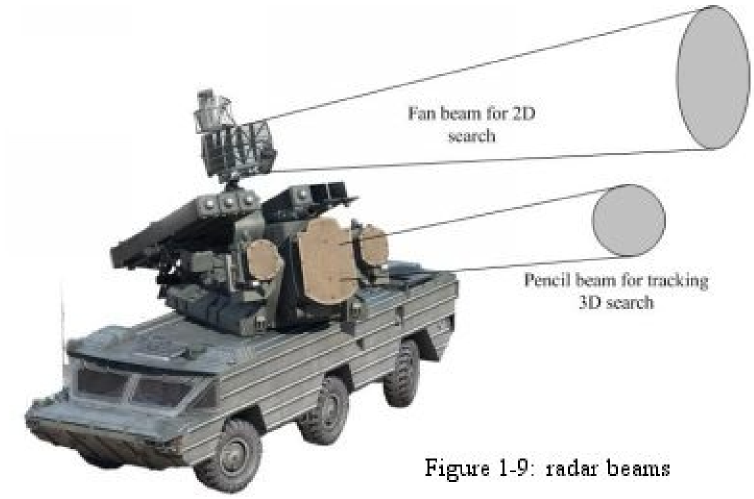


Figure 1-9: radar beams

Figure 1-10: Plain position indicators
(Source: SAM simulator, Wikipedia)

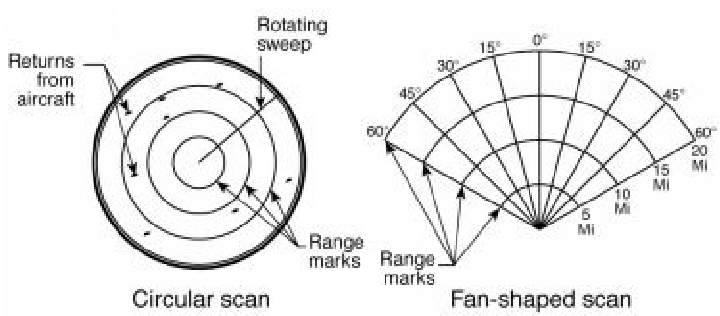


Figure 1-11: Plain position indicators

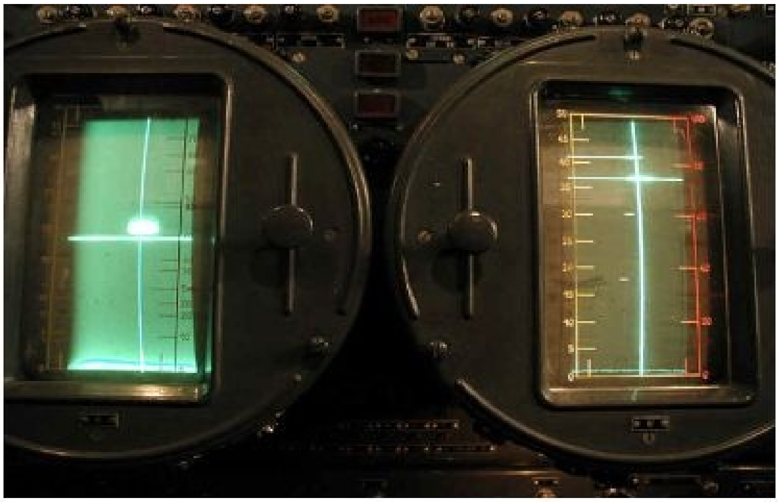


Figure 1-12: F scopes
(Source: tertraedar.org)

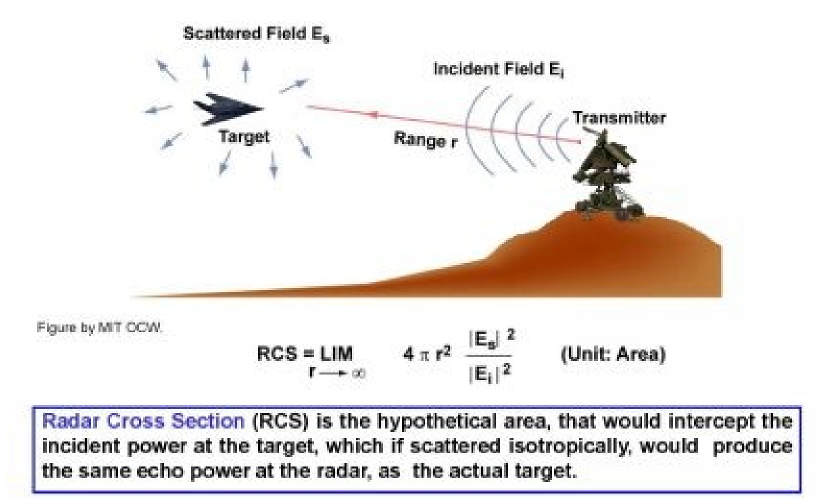


Figure 1-13: Radar cross sections
(Source: IEEE AES Society)

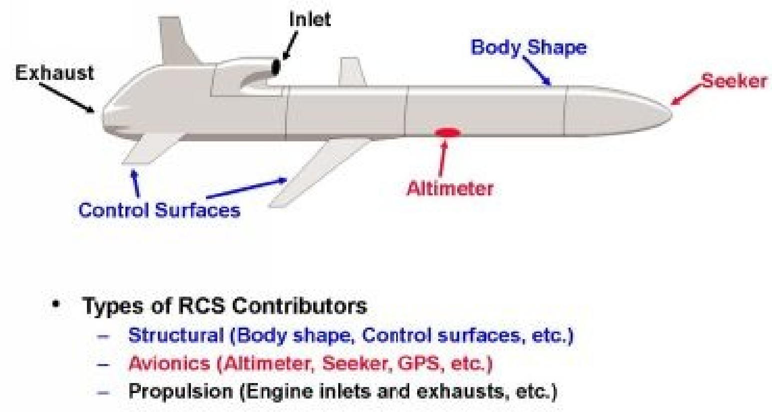


Figure 1-14: types of RCS contribution
(Source: IEEE AES Society)

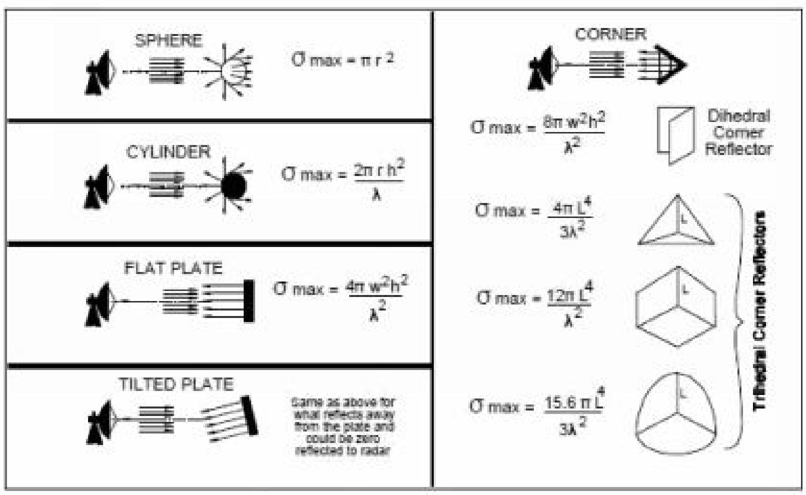


Figure 1-15: Radar cross sections of simple objects

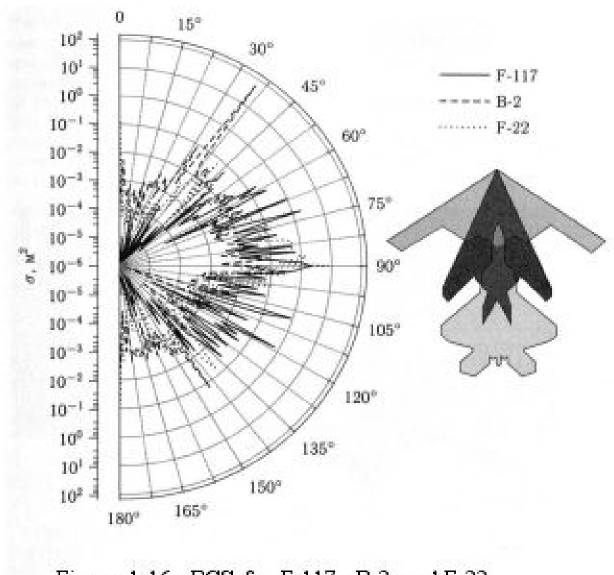


Figure 1-16: RCS for F-117, B-2 and F-22
(Source: Harakteristiki radiolokacionih Zametnosti Letalnih Aparatov

Quantity	Full Scale	Subscale
Length	L	L´ = L / S
Wavelength	λ	λ´ = λ / S
Frequency	f	f´ = S f
Time	t	t´ = t / S
Permittivity	ε	ε´ = ε
Permeability	μ	μ´ = μ
Conductivity	g	g´ = S g
Radar Cross Section	σ	σ´ = σ / S²

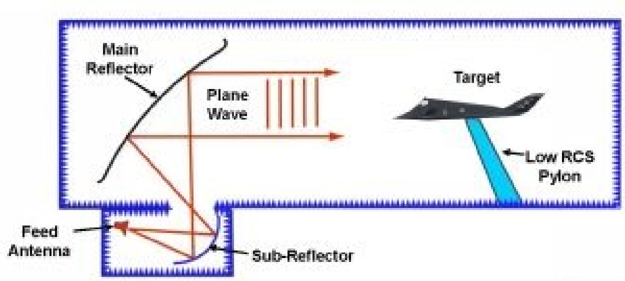


Figure 1-17: RCS scaling and measuring in the anechoic chamber
(Source: IEE AES Society)

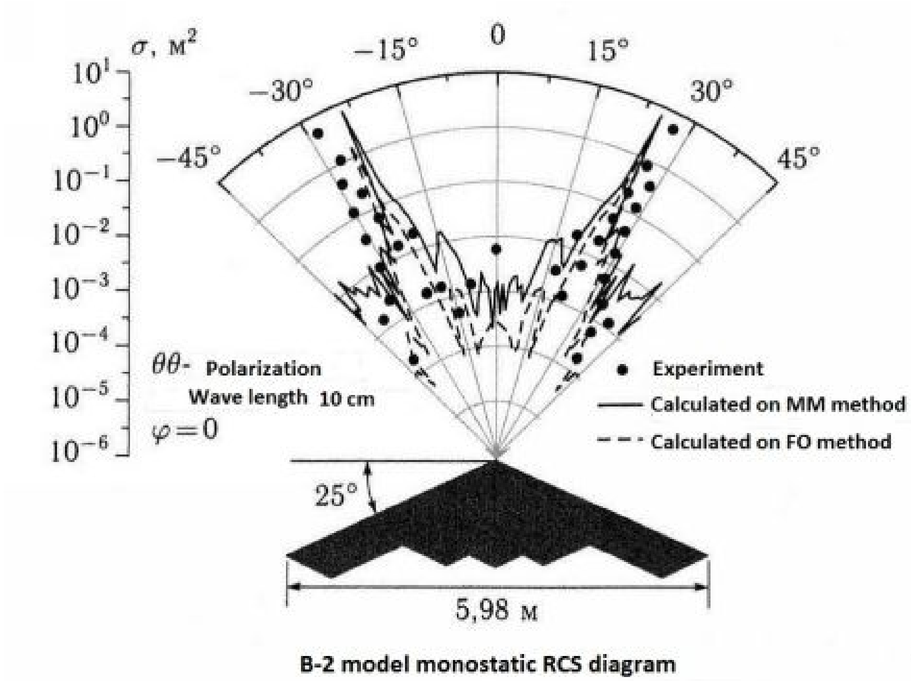


Figure 1-18:B-2 shape and monostatic RCS diagram
(Source: Harakteristiki radiolokacionih Zametnosti Letalnih Aparatov)

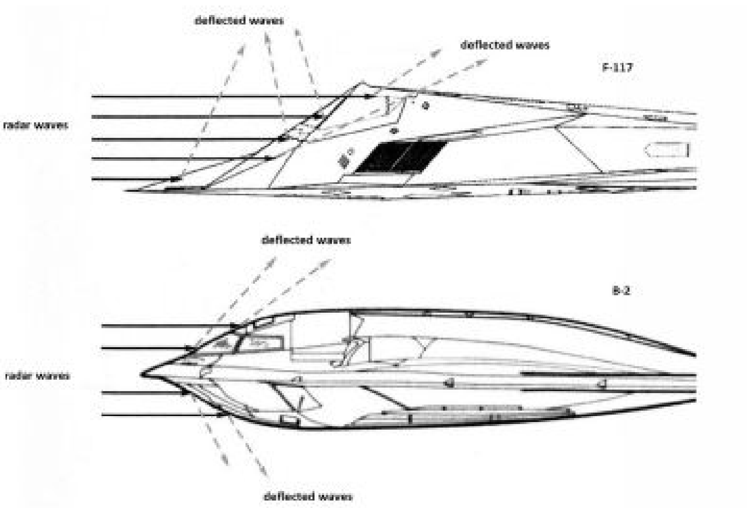


Figure 1-19: F-117 and B-2 radar beam deflection
(Source: Harakteristiki radiolokacionih Zametnosti Letalnih Aparatov)

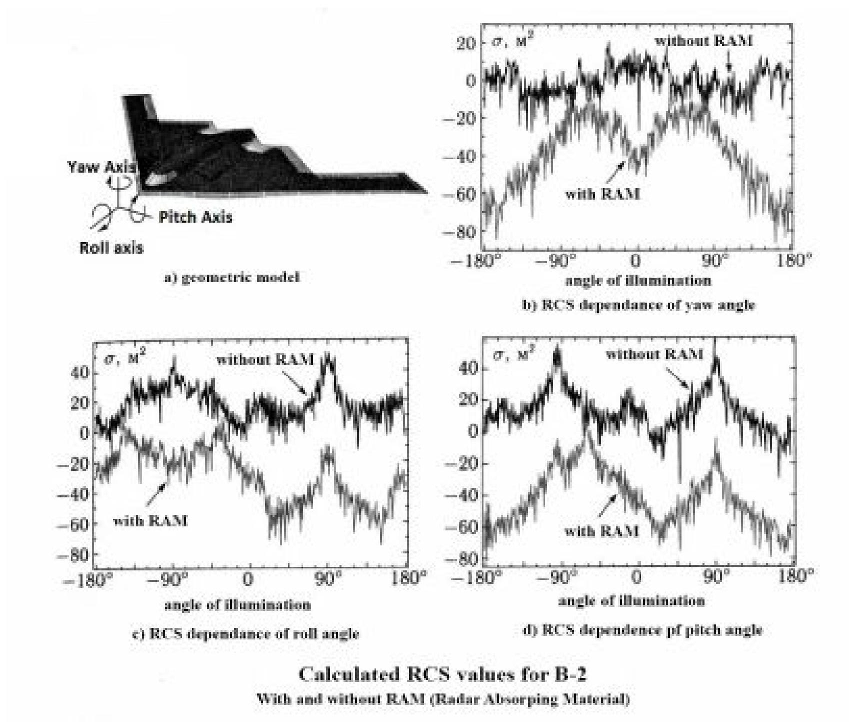


Figure 1-20: B-2 calculated RCS values
(Source: Harakteristiki radiolokacionih Zametnosti Letalnih Aparatov)

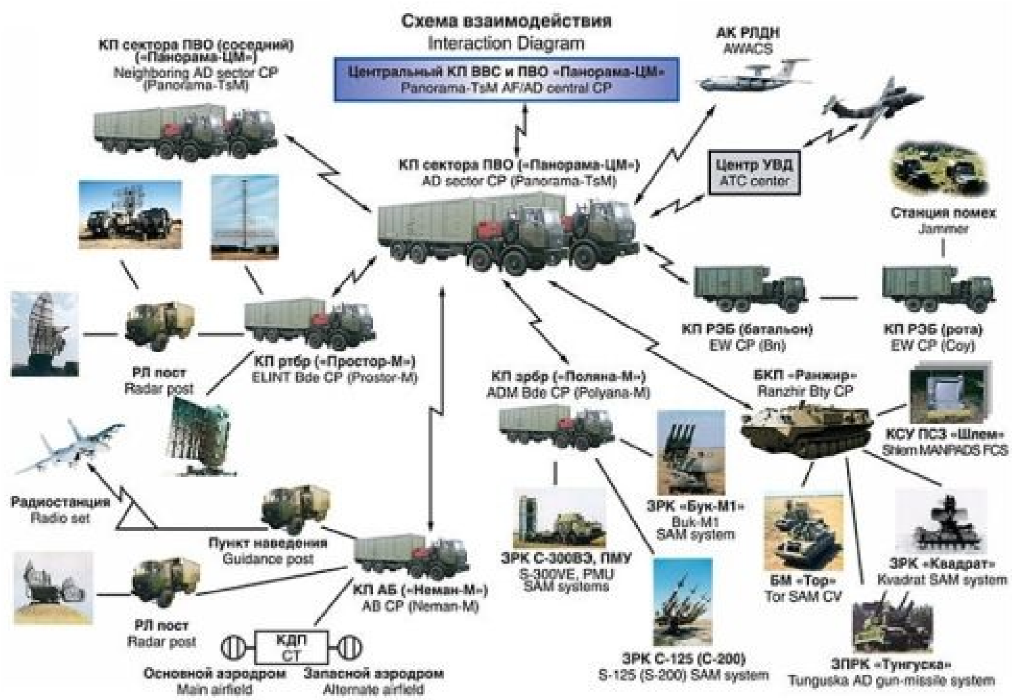


Figure 1-21: IADS
(Source: ausairpower.net)

Figure 1-22: EA-6B Prowler, electronic warfare specialized airplane. Extensively used in over Yugoslav SEAD missions (Source: USN)

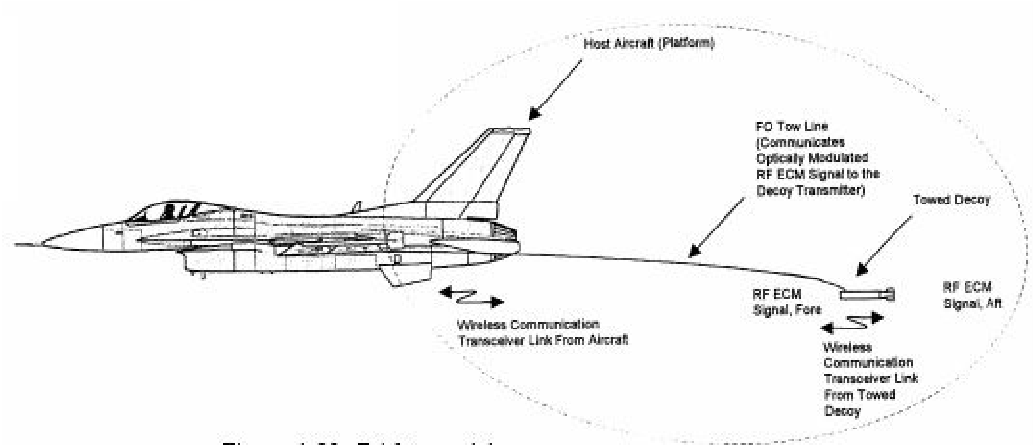


Figure 1-23: F-16 towed decoy
(Source: ausairpower.net)

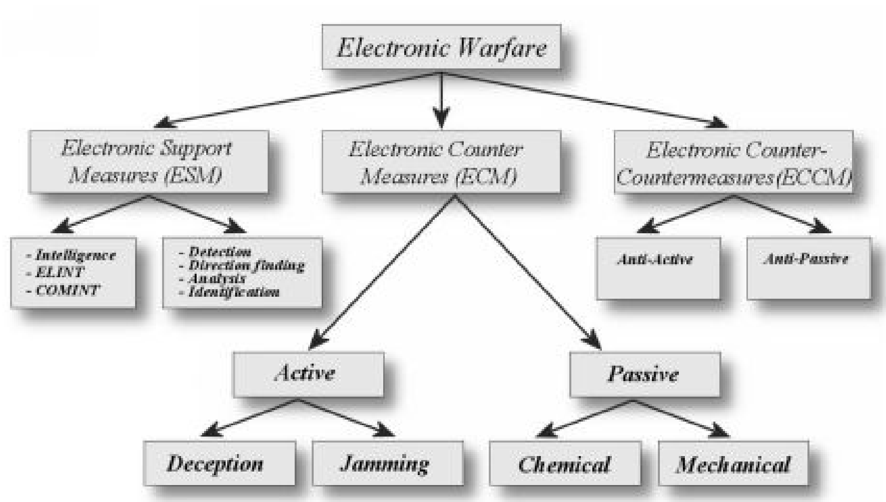


Figure 1-24: Electronic warfare

Chapter Two

Stealth

Stealth refers to the act of trying to hide or evade detection. World War II speeded up development of radars and in parallel the first countermeasures which main intention was to confuse and jam enemy radars. Sometimes around mid-war, the idea of stealth airplane started to appear. Minimizing aircraft radar return was an idea that occurred to British engineers during World War II. In August 1941, British researchers submitted a round of proposals for modifications to aircraft to render them “undetectable by normal RDF” or radar. Their plan was to adjust the aircraft’s radiation to match the background level of radiation from the air around it. Increasing the resistivity of the aircraft’s skin might short-circuit the radio wave; and instead of reflecting back, the wave could be shunted into a gap where the wavelength would be impeded. If material with the right intrinsic impedance was found, a modified matching system could prevent reflection, but only at certain frequencies.

Although they never took the idea beyond a few theoretical papers, these British engineers had hit upon a concept that would become much more compelling by the 1960s. If an aircraft could perhaps be shaped to make the return signal less powerful, the net effect would be to make the aircraft appear on the radar operator’s scope later than expected, or perhaps not at all, thereby giving the aircraft an added measure of surprise.

Historically, the first attempt towards the construction of an aircraft with “low observability” characteristics is considered to be the German Horten (Ho-229 or also designated the Go-229) built a little before the end of WWII. That aircraft, which never saw operational action, is said to incorporate some special graphite paint absorbing radar waves. In addition to the aircraft's “flying wing” shape, the majority of the Ho 229's wooden skin was bonded together using carbon - impregnated plywood resins designed with the purported intention of absorbing radar waves. Reimar Horten claimed that he wanted to add charcoal to the adhesive layers of the plywood skin of the production model to render it invisible to radar, because the charcoal “should diffuse radar beams, and make the aircraft invisible on radar. This statement was published in his 1983 co-authored book Nurflugel (translates as “only the wing”). While this statement refers to the never-made production model, it seems possible that the experimental charcoal addition could have been used on the Horten Ho 229 V3

prototype. The mere mention of early stealth technology sparked the imagination of aircraft enthusiasts across the world and spurred vibrant debate within the aviation community (**Figure 2-1**).

In early flight tests, the Horten attained a level speed of 497 mph but the prototype crashed during landing and was destroyed. Gotha still had production prototypes in work when US troops captured the Friedrichsroda plant in late April 1945. At that time, one Go 229 prototype was being prepared for flight testing, and several others were in various stages of production. Had the aircraft gone into service, its estimated maximum speed would have been a formidable 977 km/h (607 mph) and its maximum ceiling about 16000 m (52,500 feet), with a range of 1899 km (1,180 miles).

Reducing radar return was not forgotten after the war. In March 1953, when the Air Force drew up specifications for a new reconnaissance aircraft, it was stipulated that “consideration will be given in the design of the vehicle to minimizing the detectability to enemy radar.” Within a decade, designers would take the first steps toward a low observable aircraft.

Stealth technology is ever increasingly becoming a paramount tool in battle especially “high technology wars” if one may occur in the future where invincibility means invincibility. Able to strike with impunity, stealth aircraft, missiles and warships are virtually invisible to most types of military sensors. The experience gained at the warfront emphasizes the need to incorporate stealth features at the design stage itself. According to conventional military wisdom, surprise is the best form of attack. With evermore sophisticated methods of detection, however, catching the enemy unawares has becoming increasingly difficult, thus paving way to the development of increasingly sophisticated technologies that help in evading the enemy's ever vigilant “eyes”. Stealth Technology essentially deals with designs and materials engineered for the military purpose of avoiding detection by radar or any other electronic system. Stealth, or anti-detection, technology is applied to vehicles (e.g., tanks, missiles, ships, and aircraft) with the goal of making the object more difficult to detect at closer and closer ranges thus providing an element of surprise in the attacks. Attacking with surprise gives the attacker more time to perform its mission and exit before the defending force can counterattack. For example, if a surface to air missile a type of antiaircraft battery defending a target observes a bomb falling and surmises that there must be a stealth aircraft in the vicinity it is still unable to respond if it cannot get a lock on the aircraft in order to feed guidance.

Stealth or low observability (l.o.), as it is scientifically known, is one of the most misunderstood and misinterpreted concepts in military aviation by the common man. Stealth aircraft are considered as invisible aircraft, which dominate the skies. With an additional boost from Hollywood action movies, stealth is today termed as the concept invincibility rather than invisibility. Though, the debate still continues on whether stealth technology can make an aircraft invincible it was found that stealth aircraft are detectable by radar.

The motive behind incorporating stealth technology in an aircraft is not just to avoid missiles being fired at is but also to give total deniability to covert operations. This is very much useful to strike targets where it is impossible to reach. Thus, we can clearly say that the job of a stealth aircraft pilot is the objective not to let others know that he was ever there. The "value" of the stealth aircraft in the combat mission is presented in **Figure 2-2.**

The Stealth Challenge

- Survive and prosper in the future environment of improved sensors, dense countermeasures, anti-radiation weapons, and emitter locators.
- Become invulnerable or invisible.

In simple terms, stealth technology allows an aircraft to be partially invisible to radar or any other means of detection. This doesn't allow the aircraft to be fully invisible on radar. Stealth technology cannot make the aircraft invisible to enemy or friendly radar. All it can do is to reduce the detection range or an aircraft. This is similar to the camouflage tactics used by soldiers in jungle warfare. Unless the soldier comes near you, you can't see him. Though this gives a clear and safe striking distance for the aircraft, there is still a threat from radar systems, which can detect stealth aircraft. Stealth technology is expanded into each of those areas which seek to detect the aircraft, ships & missiles. Thus, it is essential to develop visual, infrared acoustic and radar stealth. However, many countries have announced that they have developed counter-stealth techniques that allow them to negate stealth.

The Stealth Approach

- Force the threats to use active sensors sparingly by employing anti-radiation missiles and electronic countermeasures.
- Decrease predictability and increase "randomness" to force the threats to increase complexity and cost of intercept receivers, surveillance, fire

control, and missiles.

- Reduce active and passive signatures and increase “hiding” to make weapon systems less visible.
- Use tactics that combine with the order of battle as well as the natural and manmade environment to enhance the effect of the reduced observables.
- Use prior knowledge and off-board sensor cueing to minimize on-board active and passive exposure.

Stealth is not only one item but rather an assemblage of techniques, which makes a system harder to find and attack. Stealth radar and data link design involves the reduction of active and passive signatures. Active signature is defined as all the observable emissions from a stealth platform: acoustic, chemical (soot and contrails), communications, radar, IFF, IR, laser, and UV. Passive signature is defined as all the observables on a stealth platform that require external illumination: magnetic and gravitational anomalies; reflection of sunlight and cold outer space; reflection of acoustic, radar, and laser illumination; and reflection of ambient RF (sometimes called splash track).

Active radar and data link signature reduction requires the use of techniques that minimize radiated power density at possible intercept receiver locations. Active signature reduction also depends on the implementation of tactics that reduce exposure time during emission. The active signature reduction methods are commonly called low probability of intercept (LPI) techniques. Passive signature reduction techniques are often called low observables (LO). They require the development of radome, antenna cavity, and antenna designs as interactive elements of a common subsystem that yields low in-band and out-of-band radar cross section (RCS). Additionally, passive radar signatures are reduced in-band by employing special antenna design techniques that minimize retroreflective echoes. Low probability of intercept system (LPIS) design is an engineering problem with a larger set of optimization constraints and hence is no different from every other modern design challenge.

Stealth Principles

Stealth technology is not a single technology. It is a combination of technologies that attempt to greatly reduce the distances at which a vehicle can be detected; in particular radar cross section reductions, but also acoustic, thermal, and other aspects. Stealth technologies aim at minimizing signatures and signals, and prevent/delay detection and identification, thus increasing the

efficiency of the vehicles own countermeasures and sensors.

The concept behind the stealth technology is very simple. As a matter of fact, it is totally the principle of reflection and absorption that makes aircraft more or less "stealthy". Ability of deflecting the incoming radar waves into another direction, in other words reducing the number of waves which otherwise will return to the radar, does this. Another concept that is followed is to absorb the incoming radar waves totally and to redirect the absorbed electromagnetic energy in another direction. Whatever may be the method used, the level of stealth an aircraft can achieve depends totally on the design and the substance with which it is made of.

The scientific theory behind the STEALTH

At the start of the Twentieth Century, a new division of mathematical physics appeared - the mathematical theory of diffraction. Using it, rigorous solutions to the problem of diffraction by a wedge, sphere, and infinite cylinder were obtained. Subsequently, other rigorous solutions were added; however, the total number of solutions was relatively small. For sufficiently short waves (in comparison with the dimensions of the body or other characteristic distances) these solutions, as a rule, are ineffective. Here the direct numerical methods also are unsuitable. Hence, an interest arose in approximation (asymptotic) methods which would allow one to investigate the diffraction of sufficiently short waves by various bodies and would lead to more precise and reliable quantitative results than doe's geometric or physical optics. Obviously, these methods must in some way be considered the most important results extracted from the mathematical theory of diffraction. In the " geometric theory of diffraction" proposed by Keller, the results obtained in the mathematical theory of diffraction of short waves were exactly the ones which were used and generalized. Here, the concept of diffraction rays advanced to the forefront. This concept was expressed rather as a physical hypothesis and was not suitable for representing the field in all of space: it was not usable where the formation of the diffraction field takes place (at the caustic, at the boundary of light and shadow, etc.). Here it is impossible to talk about rays, and one must use a wave interpretation.

There is one name that particularly sticks out of the numerous researchers in that field after WWII. That is the name of Pyotr Ya. Ufimtsev (**Figure 2-3**). Pyotr Ufimtsev was born into a peasant family in the village of Ust-Charysh Pristan, in the Altai region, of the former USSR. At the age of 3 his father was repressed by the regime and later died in a forced labor camp (GULAG system). In 1949 Ufimtsev finished school and entered the physics-mathematics department at Almaty State University (now in Kazakhstan). Because of progressing nearsightedness he had to move in 1952 from Almaty to a specialized clinic located in Odessa, Ukrainian SSR. At the same year he continued his studies at the Odessa State University. After graduating from university in 1954 he was selected to work at the Scientific Research Institute-108 (later renamed to Central Research Radio Engineering Institute).

How to make airplane to fly more discreetly was studied in a secret Russian

radar institute known as Institute 108. The institute was and still is located in Moscow and conducts fundamental research in fields off radio-physics, radio-technics, physical and quantum electronics and informatics. It was established in 1953 as an institute of the USSR Academy of Sciences. In 1957 by a decision of the Central Committee of the CPSU and the Council of Ministers the institute was assigned a task of establishing stations, that would receive signals of Sputnik 1. There were very few professional stations in the USSR at the time, and the institute cooperated with radio amateurs throughout the country and provided necessary equipment to 30 selected large DOSAAF amateur radio clubs from the Baltic Sea to the Pacific Ocean.

Theoretically, STEALTH concept is very simple. If the radar signal from the plane is not deflected toward radar source but deflected on the side, the target in the air practically becomes invisible for the radar.

To achieve this, a lot of research is required to find an optimal form which will deflect these signals away from the receiver. Dr. Ufimtsev started 1954 to work on this problem. He began developing a high-frequency asymptotic theory for predicting the scattering of electromagnetic waves from two-dimensional and three-dimensional objects. Among such objects were the finite size bodies of revolution (disk, finite cylinder with flat bases, finite cone, finite paraboloid, spherical segment, finite thin wire). This theory is now well known as the "Physical Theory of Diffraction (PTD)". The performed work showed theoretical possibilities for large objects, such as military aircrafts, to reduce Radar Cross Section (RCS). RCS is the hypothetical area required to intercept the transmitted power density at the target such that if the total intercepted power were re-radiated isotropically, the power density actually observed at the receiver is produced.

Traditional methods simply could not satisfy this purpose; therefore, scientists needed to look for a more unorthodox approach. After 6 years of theoretical research, a book was published where algorithms explain methods of radar deflection. By this theory, unique aircraft shape can be created. Logically, it would have made sense to start the planning of a new aircraft immediately. It turned out that the shape proposed by Ufimtsev was completely out of line with that of the aircraft design and production at that time.

It was the step into unknown, out of ordinary. In theory, it is possible to make the airplane invisible to the radar. The problem was that the airplane shall be

made from many flat surfaces as possible, which is by all aerodynamics principles of the day, not feasible. The shape shall be changed completely. At that time, it was goal of every aeronautical engineer and designer to create an aerodynamically ideal form of aircraft. The new form was so un-orthodox, and it was not taken seriously by aviation specialists. The general opinion was that the form is not possible and that the airplane with that aerodynamic form would not be able to fly at all. The Soviets even never looked into it thoroughly enough and could not understand the new concept. By the orders from higher instances, Ufimtsev was not allowed to continue work in this direction. With this, the unique discovery became useless. The interest for theoretical ideas began to fade. The theoretical department took on a lesser role in the institute and after some time it was disbanded. The Soviet government did not realize the true value of what Ufimtsev discovered. In the Soviet society, scientific researchers were more or less connected with the military projects. Results obtained through researches were evaluated and if authorities decided that there was no significant military or economic value they may gave permission to be published. Ufimtsev also gained permission to publish internationally his research results.

For his theoretical work, Pyotr Ya. Ufimtsev received his PhD in Electrical Engineering from the Central Research Radio Engineering Institute of the Defence Ministry 1959. He received next PhD of Science in Theoretical and Mathematical Physics from St. Petersburg University 1970.

The first results of PTD were collected in the book: Method of Edge Waves in the Physical Theory of Diffraction, published by Soviet Radio in Moscow, 1962. In 1971 this book was translated into English with the same title by U.S. Air Force, Foreign Technology Division (National Air Intelligence Center), Wright-Patterson AFB, OH, 1971...in just few years, this translation became "The Rosetta Stone" for the stealth program. PTD became an "industrial strength" theory in comparison with the "university academic" approaches. A stealth engineer at Lockheed, Denys Overholser, had read the publication and realized that Ufimtsev had created the mathematical theory and tools to do finite analysis of radar reflection. This discovery paved the road in the design of the first true stealth airplane, the Lockheed F-117.

The physical theory of diffraction (PTD) that Professor Ufimtsev introduced in the 1950s - a methodology for approximate evaluation at high enough frequency of the scattering from a body, especially a body of complicated shape - has proven to be a truly great idea. Like many good theories, PTD is much

easier to apply than to explain. For that reason, in this book just very basic principles of PTD are explained (**Figure 2-4**).

First of all, PTD is based on two important principles which it will be convenient to refer to here as the physical principle and the geometrical principle. The physical principle shows how the scattered field at a point outside a scattering body can be determined from an integral of appropriate field quantities over the surface of the body. In acoustics these quantities are the pressure at a hard surface, the normal velocity at a soft surface, both at an impedance boundary or the surface of a penetrable body. In electromagnetics they are the tangential magnetic and electric fields at an impedance boundary or the surface of a penetrable body (**Figure 2-5**).

The geometrical principle states that at high enough frequency, when the wave-length is small enough compared to the critical dimensions of the scattering body, the surface integrals can be evaluated asymptotically to yield a description of the total field outside the body in terms of geometrical rays, including diffracted rays. The change in field amplitude along a ray can be calculated geometrically by tracing the divergence and convergence of ray bundles except in the regions surrounding (a) a geometrical shadow boundary, for which ray tracing predicts a field discontinuity across the boundary, and (b) a caustic, that is, a locus where adjacent geometrical rays meet or cross (such as, in the simplest case, a focal point), at which ray tracing predicts an infinite field. The correct value for the field in these regions, which shrink as frequency increases, can be found by using uniform asymptotic techniques to evaluate the surface integrals.

One of the important features of PTD is this ability to calculate the field accurately in shadow boundary and caustic regions. It is especially important in low observables design because we are often interested in far-field scattering of a plane wave from a body with straight or slightly curved edges, a configuration for which parts of the far-field region lie in caustic regions (**Figure 2-6**).

The other major advantages of PTD arise from the way the surface fields are handled. There is a uniform part which is defined everywhere on the surface and a nonuniform part that serves as a correction term. For electromagnetics the uniform part is usually, though not always, given by the physical optics (PO) approximation, namely that the surface fields at a point are the same as if the point lay on an infinite plane surface tangent to the actual body at the point and

with the same boundary conditions as at the point. For acoustics the uniform part is usually given by the analogous approximation (**Figure 2-7**).

The basic idea of PTD is that the diffracted field is considered as the radiation generated by the scattering sources (currents) induced on the objects. The so-called uniform and nonuniform scattering sources are introduced in PTD. Uniform sources are defined as sources induced on the infinite plane tangent to the object at a source point. Nonuniform sources are caused by any deviation of the scattering surface from the tangent plane. For large convex objects with sharp edges, the basic contributions to the scattered field are produced by the uniform sources and by those nonuniform sources that concentrate near edges (often called fringe sources) (**Figure 2-8**).

The integration of uniform sources leads to the physical optics (PO) approximation for the scattered field. The PTD is the natural extension of the PO approximation, taking into account the additional field created by the nonuniform/fringe sources.

PTD can find accurately the reflection and diffraction from a body of complicated shape without having to match the entire body to canonical problems, just the regions that give rise to diffraction. PTD also minimizes the difficulty of reconciling the geometries of the body and of the canonical problem. the third and the most point is very important in low observable work and that is the PTD yields diffracted rays in all directions from each element of a linear diffracting feature rather than just in directions on the well-known diffraction cone. where the off-cone rays can sometimes yield the strongest fields in a region.

As his research was not directly related to the military programs, Dr. Ufimtsev was allowed to participate in the international conferences. In 1989 he participated at the conference in Stockholm, Sweden. At the conference he meat a group of US scientist who introduced themselves as Dr. Ufimtsev “students”. It was surprising for Dr. Ufimtsev because he didn’t have students, especially not the Americans one. Those scientists were involved in the SETALTH program. Dr. Ufimtsev got an offer to move to US and work as a visiting professor at the California University, L. A. which he accepted and moved there in 1990.

Dr. Ufimtsev was affiliated with several research and academic institutions, including the Institute of Radio Engineering and Electronics of the Academy of

Sciences (Moscow, Russia); the Moscow Aviation Institute (Russia); Northrop-Grumman Corp. (California, USA); and the University of California at Los Angeles and Irvine. As a Guest Professor, he taught courses on diffraction theory at Singapore National University; Air Force Institute of Technology; Moscow State University; Sienna University in Italy; and Dogus University in Istanbul.

In his two books, "Theory of Edge Diffraction in Electromagnetics" and "Fundamentals of the Physical Theory of Diffraction" P.Ya. Ufimtsev presented the further development and application of PTD and its validation by the exact mathematical theory. In particular, a new version of PTD, based on the concept of elementary edge waves, is presented in his book Fundamentals of the Physical Theory of Diffraction.

PTD is not only related to the STEALTH but is it universal and with appropriate modifications the modern PTD can be utilized for the solution to many practical problems. Among them are the design of microwave antennas, mobile radio communication, construction of acoustic barriers to decrease a noise level, evaluation of radar cross sections for large objects such as tanks, ships, missiles, etc.

Disadvantages of STEALTH

During the Cold War, U.S. forces focused on defeating the Warsaw Pact military in their homeland. This required an air force that could maintain air superiority over all battlefields in Soviet Union. However, the leadership of the Warsaw Pact, preferred to defeat their opponents with long range strategic missiles protected by heavy air defences formed with surface-to-air missiles (SAMs). This exposed penetrating U.S. reconnaissance and bombing aircraft to heavy defences. U.S. force structure compelled Russia to focus on detection and tracking technologies to counter U.S. Air Force asset penetration into its airspace. These strategic approaches resulted in the expansion of U.S. interest in low observables and Soviet Russia’s efforts to form a strong air defense by means of more powerful acquisition systems and SAM launchers.

These challenges reveal that stealth technology is an inevitable requirement for today’s modern forces to dominate the battlefield. Its many advantages give the user tactical combat superiority and an overwhelming dominance over an opponent. However, designing, manufacturing, operating and maintaining stealth assets has some cons. The use of the terms cons, disadvantages or drawbacks

here does not intend to thwart advances in this sophisticated military technology, but it implies that there are some challenges to deploying these technologies. These challenges must be balanced by designers and users.

The first of these drawbacks is the poor aerodynamic properties common to stealth airframes at the time when serious STEALTH programs started. Rather than aerodynamic perfection, stealth aircraft are designed according to requirements for RCS reduction, and in general this results in handling difficulties. Most modern aircraft are made unstable at one axis for greater maneuverability; however, stealth aircraft are usually unstable in all axes. Unlike other modern fighters, stealth assets require highly redundant, fly-by-wire systems for flight safety, which increase the cost and add extra weight to the airframe. During training and experimental flights, there were many failures of these flight control systems, some of which resulted in crashes; one known B-2 crash, one of seven F-117 crashes, and both F22 crashes were related to flight control unit malfunctions. Moreover, most stealth aircraft do not have engines with afterburners, thus they do not have high speed performance, and are not suitable for dogfighting. The F-22 Raptor and F-35 Lighting are an exception and may be a future solution to this problem. It is both an agile and stealthy air superiority fighter, and that is why its shape is more conventional than other stealth assets.

The second disadvantage of stealth aircraft is the requirement to either restrict electromagnetic emissions completely or emit them in a very careful manner, such as via LPI radars. Fully autonomous systems and applications using different systems, other than radar, reduce this risk; however, these systems have many constraints that limit the operational capability of the aircraft. LPI is a potential remedy and is a property of radar that, because of its low power, wide bandwidth, frequency variability, or other design attributes, makes it difficult for it to be detected by means of a passive intercept receiver. So, radars and radio and data connection methods, based on the same principle, are realistic solutions for remaining stealthy. LPI technology is more necessary to low observables than any other asset. LPI can be used to support systems, such as altimeters, tactical airborne targeting, surveillance and navigation, while it also matches with other stealthy qualifications. However, such sophisticated LPI systems, which require continuous development to counter new receiver designs, result in very high costs and deployment of complex electronically instrumentation and software.

Another drawback is the high maintenance costs associated with stealth. To remain low observable, an aircraft's surfaces must sustain their faultlessness. Surfaces must be examined very carefully, considering the fact that even an improperly tightened screw might degrade the stealthiness of an aircraft. All RAM coated parts and special paintings must be treated before each mission. Moreover, this kind of maintenance requires special shelters, such as the B-2’s climate-controlled hangars. After each sortie, B-2 Spirit has to be maintained for nearly 120 hours with experienced staff and high-tech automated devices. It is preferable to deploy these aircraft on missions from their home bases only where they can be prepared for flight. The issue is that long range sorties conducted from the homeland against overseas targets still places a serious economic burden on stealth aircraft operators.

The fourth disadvantage is that stealth aircraft are limited by the amount of ordnance they can carry. This is because in full stealth mode, aircraft are required to carry all of their ordnance internally, at least until the time when stealth weapons become operational. Thus, pre-operational intelligence is critical and the judicious use of ordnance is important, as re-attack of targets is limited by inventory. Furthermore, when the weapon bays are opened even for just a few seconds, the RCS increases which raises an enemy’s probability of detection. Another drawback of stealth aircraft is their visual signatures. Although decreased by paintings, night missions (dependency on nights and weather conditions is another drawback), and other camouflage tactics, stealth aircraft are still visible to the naked eye. Currently, experiments are being conducted to develop approaches for total cancellation of visual illumination; however, there are no known applications of such a system on operational stealth aircraft at this time.

The sixth disadvantage is the negative reaction of the public to aircraft failures. Based on mission experience during various wars, stealth aircraft have proven to be extremely successful. However, there are several known failures that have had a negative influence on public opinion. Incidents include the shoot down of an F-117 (and there are speculations that more than one F-117 took severe damage from enemy fire) on March 27 1999 during the bombing of Serbia. Other losses include shoot downs of U-2 Dragon Lady’s and several low observable UAVs during the Cold War. Normally, such small numbers of shoot down incidents over battlefields and other losses of military aircraft during training are neglected. But, the loss of such expensive military assets, which are thought to be impervious to enemy defences, receives significant public interest

In addition to the shoot down of the F-117 over Serbian airspace, eight F-117s, two F-22A Raptors and one B-2A Spirit have been lost during training flights. There are also speculations that one B-2 was lost during the combat mission. This will be discussed in detail in chapter 8.

The final and the most important con of stealth technology is the cost. Cost is affected by three factors. The first factor is the level of effort required to achieve a perfect low observable capability. Though perfection has not been provided, gained capabilities have taken a very long time to achieve and have come at a high cost. These efforts have been effective, but designers have worked hard to find methods of defeating radars and other sensor systems.

The second cost factor is the total cost of improving operational effectiveness of stealth assets using other technologies, such as complex fly by wire systems, high-tech computer and control units, special super cruise engines, LPI radars, navigation, precision targeting systems, and stealth armaments, which are under development. These factors require spending exorbitant amounts of money. Moreover, production of all three currently operational stealth aircraft reveals that total program expense, together with sunk costs of these projects per aircraft, is extremely high. The reason for this is the increase in single airframe cost, when projected production amounts are decreased to relatively small numbers due to cost growth associated with unexpected commitments or changes in requirements. Moreover, it is difficult to recover development costs through sales to other nations, a common practice for non-stealth weapons systems. Stealth assets are protected from foreign military sales due to security concerns. In this context, the U.S. Congress has banned their sales by declaring their critical technology, even though these sales would likely to recover some of these costs.

The third cost factor concerns operational expenses. For example, while the B-2 Spirit can be deployed anywhere in the world within 12 hours, it is operationally crippled by its exorbitant replacement cost and results in a challenging risk/benefit analysis when considering its deployment

Despite all these drawbacks and challenges in producing stealth assets, stealth technology has fulfilled the air force requirements for battlefield survivability since its first applications. Thus, many assets have been developed and deployed. These airframes used stealth technology in favor of their tactical combat superiority and overwhelming dominance over an opponent. In this

context, specially designed air defences with new radar systems and tactics have been required to withstand against low observables.

Popular perceptions of stealth, especially propagated in mass media, appear to have little connection with the hard science involved. The notion that stealth confers invisibility to all radars from all directions is perhaps the most pernicious aspect of this mythology, the belief in which has been actively encouraged by defence contractors and government bureaucracies, usually to justify purchases of underperforming stealth or indeed ‘quasi-stealth’ products.

The ground truth is much less attractive – radars operate across a wide range of wavelengths, from the HF band at tens of metres up to the Ka-Band in millimetres. Devising stealthy shapes that are effective from all directions against all wavelengths is simply impossible, at best a real design can aim to make the vehicle very stealthy against radars in some bands, from some directions.

By far the best performer to date is the Northrop B-2A Spirit heavy bomber. Its superlative shaping design is effective from the metric VHF band up to the sub-centimetric Ku/K/Ka-bands, and effective from all azimuths, providing a genuine “all aspect” stealth capability.

Fighters have generally been optimised by shaping to perform best between the decimetre S-Band and sub-centimeter Ku-band, since these are the bands in which most surveillance radars, acquisition radars, Surface to Air Missile engagement radars, fighter-borne air intercept radars, and missile radar seekers operate. Optimization of stealth shaping by aspect varies widely in fighter designs, with the F-22A Raptor remaining by far the best design to date, with excellent stealth performance in the nose and tail sectors, and very good performance from the sides. Computer modeling of later designs – the F-35, Russian PAK-FA/Su-57 and Chinese J-20 - shows significantly worse stealth performance from behind, and in most instances, from the sides. This is not open to argument, as sufficient high-quality images are available to construct accurate shaping models, and perform simulations using accurate software models.

A curious aspect of these poor design choices in stealth shaping is that not all of them were necessary and appear to reflect a lack of discipline in design offices where other criteria were put first. In the F-35 the choices were driven by the STOVL variant configuration and a marketing want for 2,000 lb internally

carried bombs, in the PAK-FA/T-50/Su-57 achieving extreme maneuver performance, and in the J-20, most likely a few per cent in supersonic drag improvement.

The major strategic issue over the coming decade will be the design, production and proliferation of counter-stealth sensors, built primarily to exploit weaknesses in existing stealth designs. Since shaping is fixed in the basic design of aircraft, there are no meaningful upgrades that can be performed once a design is established and in production. Claims otherwise are simply marketing mythology.

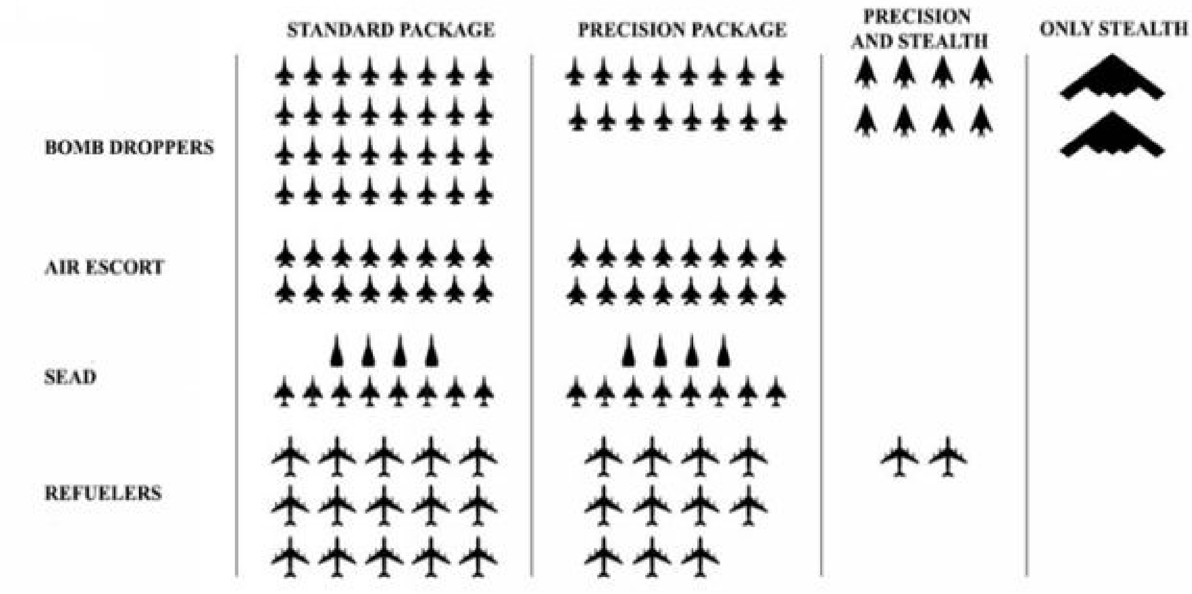


Figure 2-2: The value of STEALTH

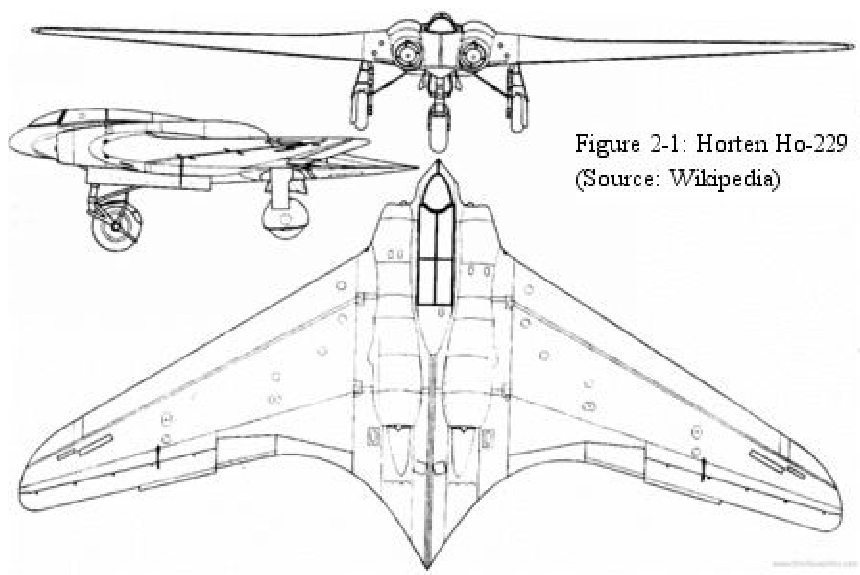
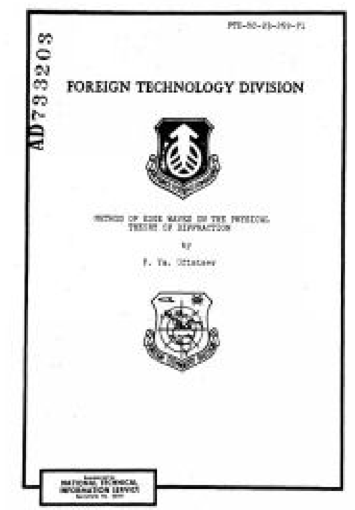


Figure 2-1: Horten Ho-229 (Go-229) (Source: Wikipedia)



AD733203

FOREIGN TECHNOLOGY DIVISION

METHOD OF EDGE WAVES IN THE PHYSICAL
THEORY OF DIFFRACTION

by

P. Ya. Ufimtsev

Figure 2-4: translated book cover page
(Source: DTIC)

Figure 2-3: Dr. Pyotr Ufimtsev, "father"
of stealth technology

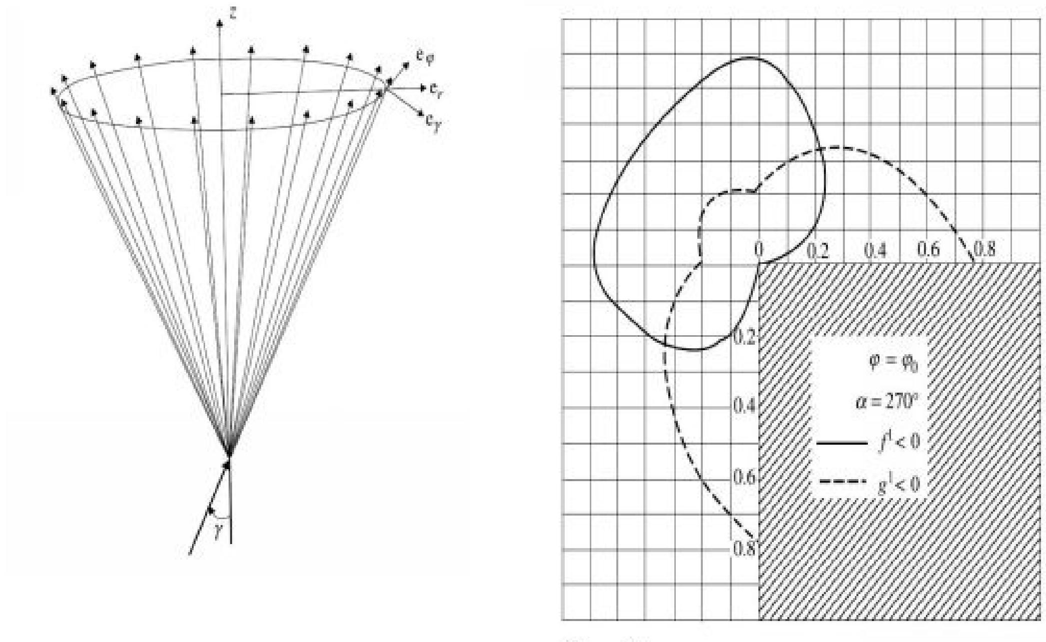


Figure 2-5: Diffraction cone and directivity patterns edge
(Source: P. Ufimtsev - Fundamentals of the physical theory of diffraction)

Figure 2-7: Diffraction rays from sharp corner (Source: Authors)

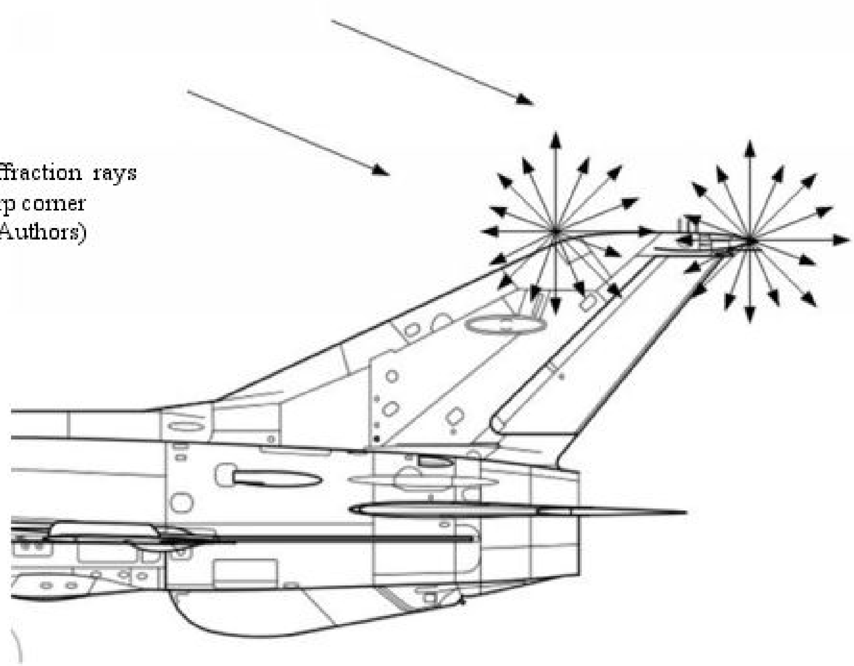
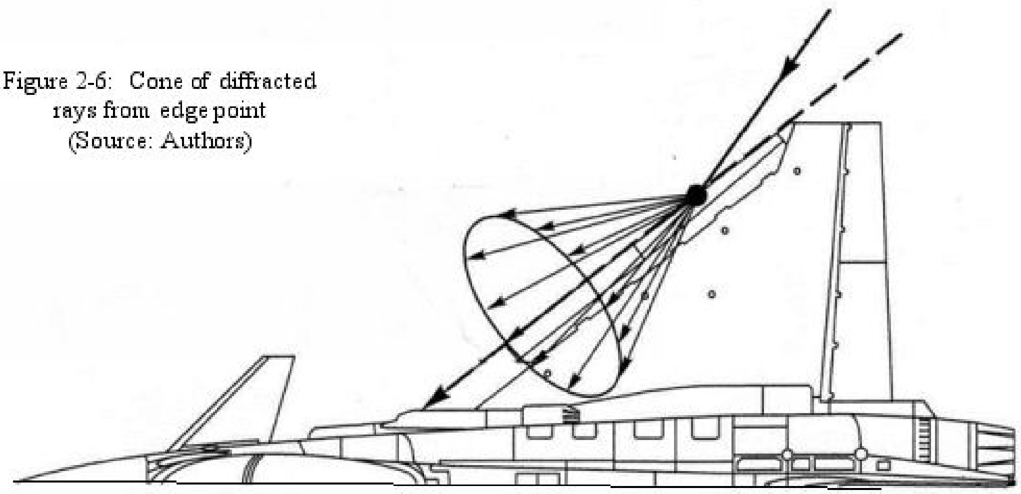


Figure 2-6: Cone of diffracted rays from edge point (Source: Authors)



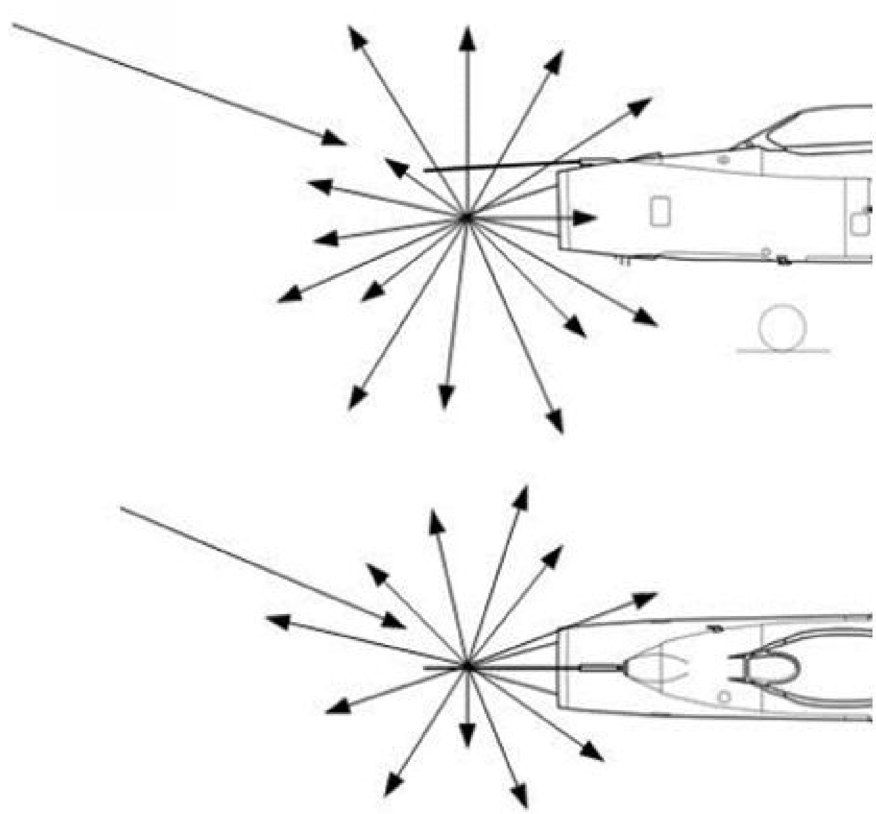


Figure 2-8: Diffraction rays from conical point (Source: Authors)

Chapter Three

Missile guidance

The design of a guided missile is a large undertaking, requiring the team effort of many engineers having expertise in the areas of aerodynamics, flight controls, structures, and propulsion, among others. The different design groups must work together to produce the most efficient weapon in terms of high accuracy and low cost.

This chapter presents a discussion and overview of missile guidance and control laws applicable to Surface-to-Air missiles (SAM's) as well as the basic equations that are used in intercepting a given target. Theoretically, the missile–target dynamics are highly nonlinear. This is due to the fact that the equations of motion are best described in an inertial coordinate system, whereas aerodynamic forces and moments are conveniently represented in the missile and target body axis system. In addition, and if optimal control theory is used to model and/or formulate the plant (or system), un-modeled dynamics or parametric perturbations usually remain in the plant modeling procedure. Furthermore, speed plays an important role in determining interceptor missile aerodynamic maneuverability.

Table 2 illustrates basic guidance concepts in surface to air missile, of which two are most common:

(a) the homing guidance system, which guides the interceptor missile to the target by means of a target seeker and an onboard computer; homing guidance can be modeled as active, semi-active, and passive;

(b) command guidance, which relies on missile guidance commands calculated at the ground launching (controlling) site and transmitted to the missile.

Guided missile (also known as guided munitions) systems (**Figure 3-1**) contain a guidance package that attempts to keep the missile on a course that will eventually lead to an intercept with the target. Most guidance surface-to-air missiles (SAMs) or air defence systems employ either homing or command guidance in order to intercept the target. At this point it is appropriate to note that short-range, shoulder-fired SAMs using IR guidance have been developed by various nations.

Electromagnetic radiation is the most popular form of energy detected by homing systems. Radar can be the primary sensor for any of the three classes of homing guidance systems, but it is best suited for semi-active and active homing. Currently, the use of electromagnetic radiation via radar in a target seeker is foremost in effectiveness. Radar is little restricted by weather or visibility but is susceptible to enemy jamming. Heat (infrared radiation) is best used with a passive seeker. It is difficult to mislead or decoy heat-seeking systems when they are used against aerial targets because the heat emitted by engines and rockets of the aerial targets is difficult to shield. With a sufficiently sensitive detector, the infrared system is very effective. Light is also useful in a passive seeker system. However, both weather and visibility restrict its use. Such a system is quite susceptible to countermeasure techniques.

Various flight paths or trajectories may be deployed with respect to fixed targets, but for moving targets special requirements must be met. In homing systems, sensing elements must be sharply directional to perceive small angular displacements between a missile and its target. Surface to air missile systems typically use command and other type of guidance.

Surface to air missile guidance is generally divided into three distinct phases: (1) boost or launch, (2) midcourse, and (3) terminal. The boost phase lasts from the time the missile leaves the launcher until the booster burns all of its fuel. The missile may or may not be actively guided during this phase. The midcourse phase, when it has a distinct existence, is usually the longest in terms of both distance and time. During this phase, guidance may or may not be explicitly required to bring the missile onto the desired course and to make certain it stays on course until it enters a zone (in parametric space) from which terminal guidance can successfully take over. The terminal phase is the last phase of guidance and must have high accuracy and fast reaction in order to ensure an intercept with the target. In this phase, the guidance seeker (if one is used) is locked onto the target, permitting the missile to be guided all the way to the target. Therefore, proper functioning of the guidance system during the terminal phase, when the missile is approaching its target, is of critical importance. A great deal of work has been done to develop extremely accurate equipment for use in terminal-phase guidance.

There are several guided systems that fall into this category. The most common ones are the short-range homing systems and some type of inertial system. These terminal systems may also be the only guidance systems used in

short-range missiles. Prelaunch aiming errors must be minimized because these errors tend to translate directly into miss distance. Subsequent to launch, the missile has certain requirements. First, the missile needs a target signal. For example, in the case of a semi-active guided missile, the target signal is the result of energy reflected from the target. The source of this energy is the interceptor, which in turn receives energy from the illuminator. Thus, subsequent to launch, the missile requires that the target be continuously illuminated. Target illumination, by itself, does not require that the interceptor track the target, although this may occur. In addition, the missile requires the presence of certain modulations on the target return, which are conveniently impressed on the illuminating signal itself. Typically, this is an 85 Hz FM ranging signal, which the missile uses to select the target from clutter or noise.

Command guidance techniques as well as other command/homing methods, which are part of the post-launch phase, can be affected in a number of ways, the more prominent of which are listed below:

Command Guidance: Command guided missiles are missiles whose guidance instructions or commands come from sources outside the missile. In this type of guidance, a tracking system that is separated from the missile is used to track both the missile and the target. Therefore, a missile seeker is not required in command guidance. The tracking system may consist of two separate tracking units, one for the missile and one for the target aircraft, or it may consist of one tracking unit that tracks both vehicles. The tracking can be accomplished using radar, optical, laser, or infrared systems. A radar beacon or infrared flare on the tail of the missile can be used to provide information to the tracking system on the location of the missile.

The target and missile ranges, elevations, and bearings are fed to a computer. Consequently, using the position and position rate information (i.e., range and range rate), the computer determines the flight path the interceptor missile should take that will result in a collision with the target. Computer at the launch point determines whether the interceptor missile is on the proper trajectory to intercept the target. If it is not, steering commands are generated by the ground computer and transmitted to the in-flight missile. Furthermore, the computer compares this computed flight path with the predicted flight path of the missile based on current tracking information and determines the correction signals required to move the missile control surfaces to change the current flight path to the new one. These signals are the command guidance and are sent to the missile

receiver via either the missile tracking system or a separate command link, such as radio. In addition to the steering instructions, the command link may be required to transfer other instructions to the missile, such as fuse arming, receiver gain setting, and warhead detonation. Finally, in command guidance, the launch point commands the missile.

Command guidance all the way to the target is used mostly with short-range missile systems because of the relatively large tracking errors that occur at long range. A disadvantage of command guidance is that the external energy source must illuminate the target often enough (i.e., high data rate) to make guidance effective. The target may thus get alerted of the illuminating radar's presence and operation, and may resort to evasive action (**Figure 3-2**, **Figure 3-3**).

Beam Rider: Beam riding is another form of command guidance. Specifically, in this type of guidance, the aircraft (target) is tracked by means of an electromagnetic beam, which may be transmitted by a ground (or ship or airborne) radar or a laser tracking system (e.g., a LADAR (**LA**ser **D**etection **A**nd **R**anging or laser radar). In order to follow or ride the beam, the interceptor missile's onboard guidance equipment includes a rearward-facing antenna, which senses the target-tracking beam. By utilizing the modulation properties of the beam, steering signals that are a function of the position of the missile with respect to the center (or the scanning axis) of the target-tracking beam are computed on board and sent to the control surfaces. These correction signals produce control surface movements intended to keep the missile as nearly as possible in the center of the target-tracking beam (or scanning axis) (**Figure 3-4**).

For this reason, the interceptor missile is said to ride the beam. Either the beam that the missile rides can track the target directly or a computer can be used to predict the direction the missile beam should be pointing in order to effect an eventual collision of the interceptor missile with the target. In this case, a separate tracker is required to track the target. Some ground-tracking systems use a V-shaped beam to track the target. In such a case, the interceptor missile rides in the bottom of the V. If the missile moves out of the V bottom, sensing circuits in the missile cause the missile to return to the bottom of the V. As long as the launch point continues to track the target, and the missile continues to ride the radar beam, the missile will intercept the target. As in any system, there are advantages and disadvantages in using one method versus another. The advantage of the beam-riding guidance technique is that it permits the launching

of a large number of missiles into the same control or target-tracking beam, since all of the guidance equipment is carried in the missile. A disadvantage of this guidance technique is that the tracking beam must be reasonably narrow to ensure intercept, thus increasing the chance of the interceptor missile losing track of the target, particularly if the target undergoes evasive manoeuvres. The problem of large tracking error for long-range targets usually restricts the use of this guidance technique to short ranges (**Figure 3-5**, **Figure 3-6**).

Command to Line of Sight (CLOS) (**Figure 3-7**): A particular type of command guidance and navigation where the missile is always to commanded in the line of sight (LOS) between the tracking unit and the aircraft is known as "command to line of sight" (CLOS) or three-point guidance. The missile is controlled to stay as close as possible on the LOS to the target after missile capture. In CLOS guidance an up-link is used to transmit guidance signals from a ground controller to the missile. More specifically, if the beam acceleration is taken into account and added to the nominal acceleration generated by the beam-rider equations, then CLOS guidance results. Thus, the beam rider acceleration command is modified to include an extra term. The beam-riding performance described above can thus be significantly improved by taking the beam motion into account. CLOS guidance is used mostly in short range air defence and antitank systems.

The following target intercept rules are possible within command / homing guidance strategies.

Pursuit: (**Figure 3-8**) In the pursuit trajectory, the interceptor missile flies directly toward the target at all times. Thus, the heading of the missile is maintained essentially along the LOS between the missile and the target by the guidance system. The missile is constantly turning during an attack. Missiles flying a pursuit course usually end up in a tail-chase situation, similar to a dog chasing a rabbit (or hound-and-hare course). Pursuit guidance is considered impractical as a homing guidance law against moving targets because of the difficult manoeuvres that are required to end the attack in a tail chase. That is, the maneuvers required of the missile become increasingly hard during the last, critical, stages of the flight. Another disadvantage of this guidance method is that the missile speed must be considerably greater than that of the target. The sharpest curvature of the missile flight path usually occurs at the end of the flight, so that at this time the missile must overtake the target. If the target attempts to evade, the last-minute angular acceleration requirements placed on

the missile could exceed the aerodynamic capability, thereby causing a large miss distance. Furthermore, near the end of the flight, the missile is usually coasting because the booster (and sustainer) motor thrusts last for only a short part of the flight. The result is that more energy is required on the part of the missile to make short-radius, high-speed turns at a time when the missile is losing speed and has the least turning capability. The most favorable application of the pursuit course guidance law is against slow-moving aircraft, or head on toward an incoming aircraft.

Figure 3-8: General pursuit guidance course

Deviated Pursuit: (**Figure 3-9**) The interceptor missile tracks the target and produces guidance commands. This guidance law is similar to pure pursuit, except that the missile heading leads the LOS by a fixed angle. When the fixed lead angle is zero, deviated pursuit becomes pure pursuit. No missile is designed to fly deviated pursuit; however, random errors and unwanted bias lines often result in a deviated pursuit course.

Lead Pursuit: A lead pursuit course is flown by an interceptor (i.e., a missile) directing its velocity vector at an angle from the target so that projectiles launched from any point on the course will impact on the target if it is within the range of the weapon. Note that the interceptor in conjunction with the missile trajectory flies lead pursuit.

Lead Collision: Lead collision is a straight-line course flown by an interceptor such that the interceptor will achieve a single given firing position. Specifically, in lead collision homing, if the target speed and heading remain constant, a constant-speed missile will fly a straight-line path to the target–missile collision. The target and missile flight paths form a single triangle with the line of sight (LOS) from the missile to the target. An obvious advantage of collision homing is that the missile is subjected to a minimum of maneuvers since the flight path approximates a straight line. The time of flight of the weapon is a constant.

Pure Collision: (**Figure 3-10**) Pure collision is a straight-line course flown by an interceptor or weapon such that it will collide with the target.

Constant Load Factor: A constant load factor course is flown by an interceptor or missile so that a constant-g load factor load on the interceptor will result in collision with the target. No missiles presently fly constant load factors. Normal acceleration is constant in this course.

Proportional Navigation: (**Figure 3-11**, **Figure 3-12**, **Figure 3-13**) The conceptual idea behind proportional navigation is that the missile should keep a constant bearing to the target at all time. As most sailors know this strategy will result in an eventual impact. Proportional navigation (also referred to as collision homing) is flown in such a manner as to change the lead angle at a rate proportional to the angular rate of the line of sight to the target. The missile measures the rotation of the LOS and turns at a rate proportional to it. Specifically, the classical proportional navigation guidance law tries to null the heading error for intercepting the target. The constant of proportionality between the turn rate and line-of-sight rate is called the navigation constant (N). In essence, the trajectory flown by the missile is heavily influenced by its navigation constant. This constant is maintained between the missile lateral acceleration (an) and the product of the line-of-sight rate (dλ/dt) and closing velocity Vc. Mathematically, proportional navigation can be expressed as:

$$a_n = NV_c(d\lambda/dt)$$

a_n = the commanded normal (or lateral) acceleration [ft/sec2] or [m/sec2],

N = the navigation constant (also known as navigation ratio, effective navigation ratio, and navigation gain), a positive real number [dimensionless],

Vc = the closing velocity [ft/sec] or [m/sec],

dλ/dt = the LOS rate measured by the missile seeker [rad/sec].

Three-Point: (**Figure 3-14**, **Figure 3-15**) In three-point guidance, the missile is constantly being steered to lie between the target tracker and target. This type of trajectory is typically used only in short-range missile systems employing command-to-line-of-sight (CLOS) or beam-rider guidance. Thus, three-point guidance refers to the ground tracker, missile, and target. Three-point guidance is also known in the literature as constant bearing guidance. Constant bearing guidance is a specialized case of proportional navigation; that is, constant-bearing guidance is obtained in the limit as $N' \rightarrow \infty$.

Hyperbolic Guidance: The guidance or control of a guided missile or the like in which the difference in the time of delay of radio signals transmitted simultaneously from two ground stations, arriving at the missile at different time intervals, controls the position of the missile. This system is based upon the geometric theorem that the locus of all points of fixed difference in distance from two base points is a hyperbola.

Finally, it should be noted that no one type of guidance is best suited for all applications. Consequently, many missile systems use more than one type of guidance, with each one operating during a certain phase of the interceptor missile's trajectory. For example, a system may use beam-rider guidance or semi-active homing from launch until midcourse, at which time the guidance mode switches to active or passive homing for more accurate tracking and guidance during the terminal phase. An advantage of this technique is that this combination allows the launching aircraft to break away from the engagement earlier than otherwise possible. Such systems are commonly referred to as composite guidance systems. Several types of guidance may also be used simultaneously to avoid countermeasures employed by the aircraft, such as the use of a decoy flare to draw an infrared homing missile off the radiation from the aircraft. However, if an active homing system is used in conjunction with a passive one, the missile may reject the flare and continue on toward the target aircraft.

Of particular significance, from the point of view of defensive weapons, is the surface-to-air missile. A surface-to-air missile is launched from the ground or from the surface of the sea against an airborne target. It is generally a defensive weapon, since its function is to intercept an enemy aircraft or an incoming missile that is approaching the point or area to be defended. In synthesizing a surface-to-air air defence missile system the designer must make two basic decisions:

(1) the method of guiding the missile, and
(2) the type of path over which it travels to the target. The homing, beam-rider (or CLOS), and command types of guidance are all applicable to surface-to-air missiles.

Before a surface-to-air missile system can go into action against any hostile airborne target, the system radar must detect the target. Detection must take place at a range long enough to take advantage of the range of the missile, for the following reasons:

(1) It may be necessary to launch a number of missiles to destroy all the targets in a group detected one at a time;

(2) it is obviously desirable to destroy the target before it comes close to the point being defended; and

(3) with many types of missile guidance, excessive accelerations are required of the missile to engage the target at close ranges.

The system radar must also be capable of acquiring and tracking a target of the specified radar cross section (RCS), and may be required to do this at low altitudes in the presence of ground or sea clutter return. Finally, there must be a high probability that a target will be detected if and only if a target exists. Closely associated with the early detection requirement is the system reaction time, defined as the time elapsing between detection of a target and the launching of a missile toward it. If this time is long, then the target would need to be detected correspondingly early during its approach.

A final comment on pursuit guidance is in order. For pursuit against a non-maneuvering target, the collision course exhibits a constant bearing property, whereby the LOS maintains a fixed direction in space; that is, the LOS moves parallel to itself in space during the engagement. Consequently, the pursuer will appear to be coming in straight at the target, though pointed off by the lead angle. If a constant bearing guidance law is adopted against a maneuvering target, the resulting pursuer trajectory no longer remains a straight line; however, it still has the desirable property that the demanded pursuer lateral acceleration is at most equal to that of the target. From a theoretical point of view, a constant-bearing guidance law would be a desirable one against both maneuvering and non-maneuvering targets. However, a constant-bearing law is difficult to implement, especially for the general case of maneuvering targets, since it requires the pursuer to be able to detect the component of target motion perpendicular to the LOS, and to adjust its own motion instantaneously, in such a way that its velocity component perpendicular to the LOS equals that of the target.

Table 2[1] Types of guidance systems

Type	**Methods of Navigation**	**Sensing Devices**	**Characteristics**
	1. Proportional	1. Radar	

Active homing	Navigation 2. Pure Pursuit 3. Deviated Pursuit	2. Infrared 3. Imaging Infrared 4. Laser 5. TV	Ground system not committed to single target.
Semi-active homing	1. Proportional Navigation 2. Pure Pursuit 3. Deviated Pursuit	1. Radar 2. Infrared 3. Imaging Infrared 4. TV 5. Laser	Ground system committed to single target. Until intercept takes place
Passive homing	1. Proportional Navigation 2. Pure Pursuit 3. Deviated Pursuit	1. Infrared 2. Visible Light 3. Electro magnetic Energy	Ground system not committed to single target. All sensing devices have limited capability compared with radar.
Command guidance	Any Method	1. Radar 2. Infrared 3. Visible Light	Ground system committed to single target. Missile dynamically linked to ground system. Ground computer required for programmed flight. Low-cost missile.
Beam Rider (or CLOS)	1. Line-of-Sight 2. Programmed	1. Radar 2. Infrared 3. Visible	Ground system committed to single target. Missile dynamically linked to ground system. Ground computer required for programmed

		Light	flight. Low-cost missile.

[1] From the Missile Guidance and Control Systems

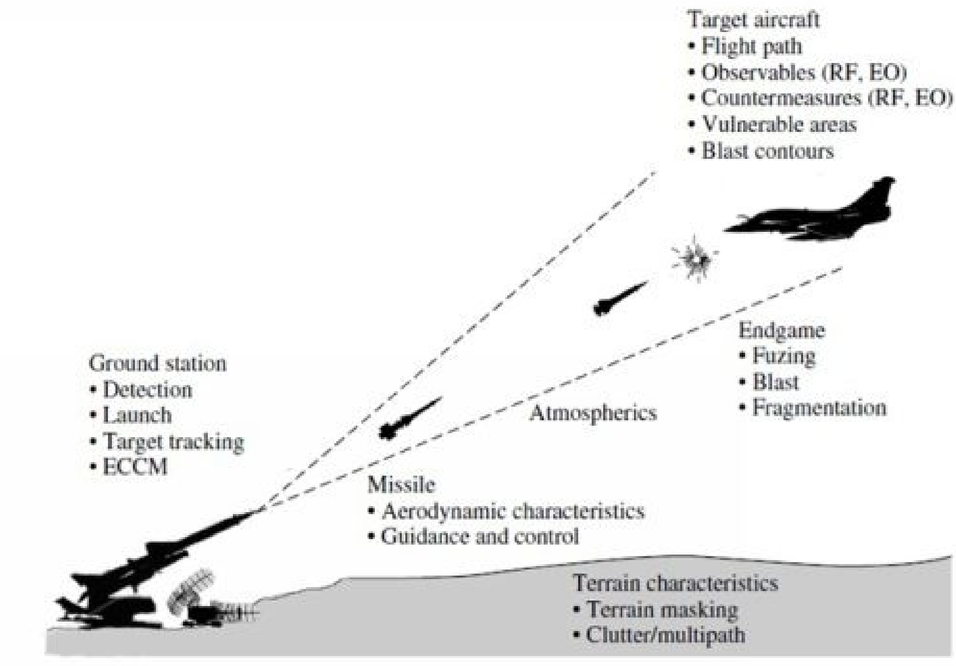


Figure 3-1: interaction between an airborne target and a SAM air defence system
(Source: Missile Guidance and Control Systems modified by authors)

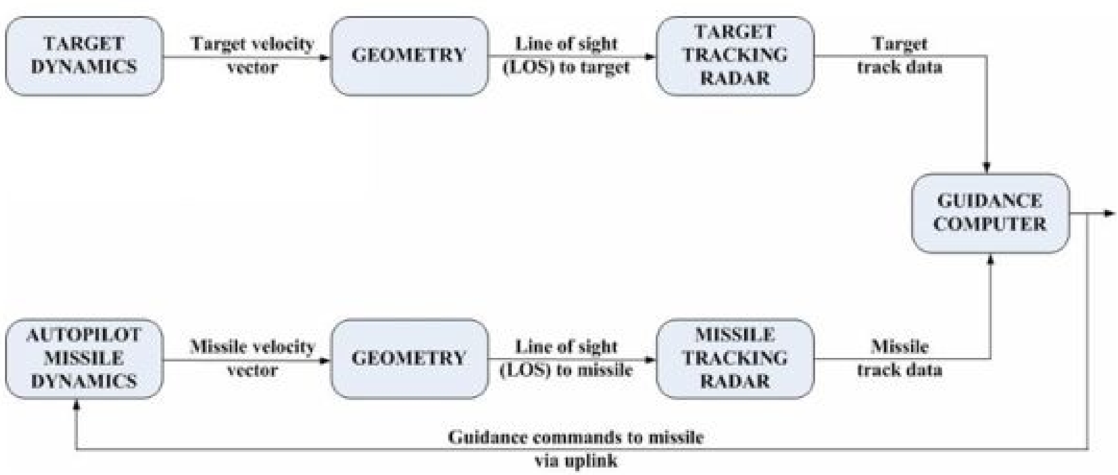
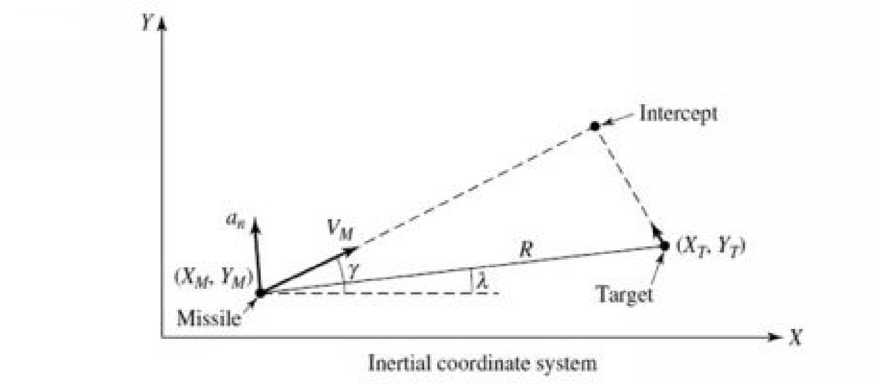


Figure 3-2: System block diagram for command guidance
(Source: authors)



Missile–target intercept geometry.

Dε- displacement from the site to the target

$\lambda\varepsilon$ - lateral displacement from the missile to the desired course

R_m - missile range

R_t - target range

θ_D - depression angle

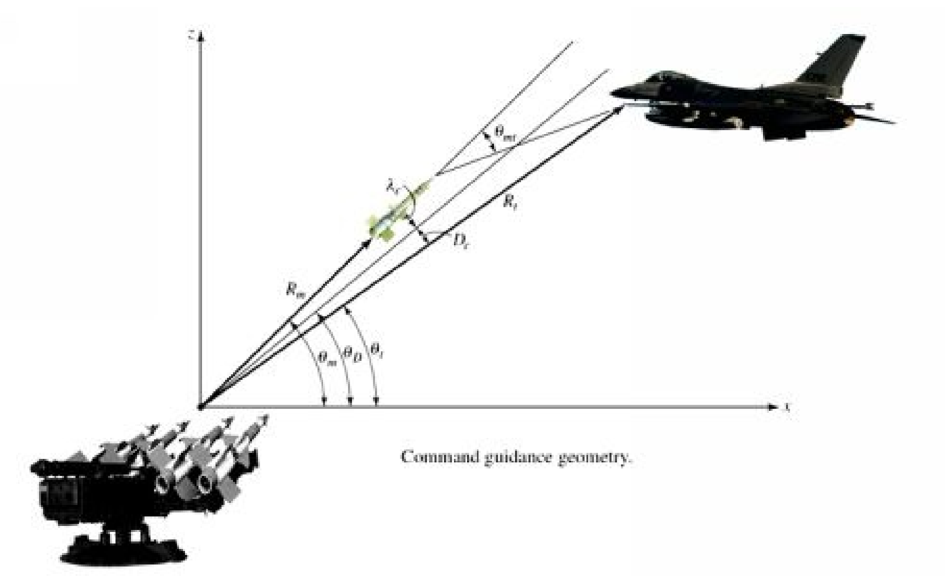
θ_m - missile depression angle

θ_t - target depression angle

Figure 3-3: Command guidance geometry

(Source: Missile Guidance and Control Systems modified by authors)

Figure 3-4: target intercept geometry
(Source: Missile Guidance and Control Systems)



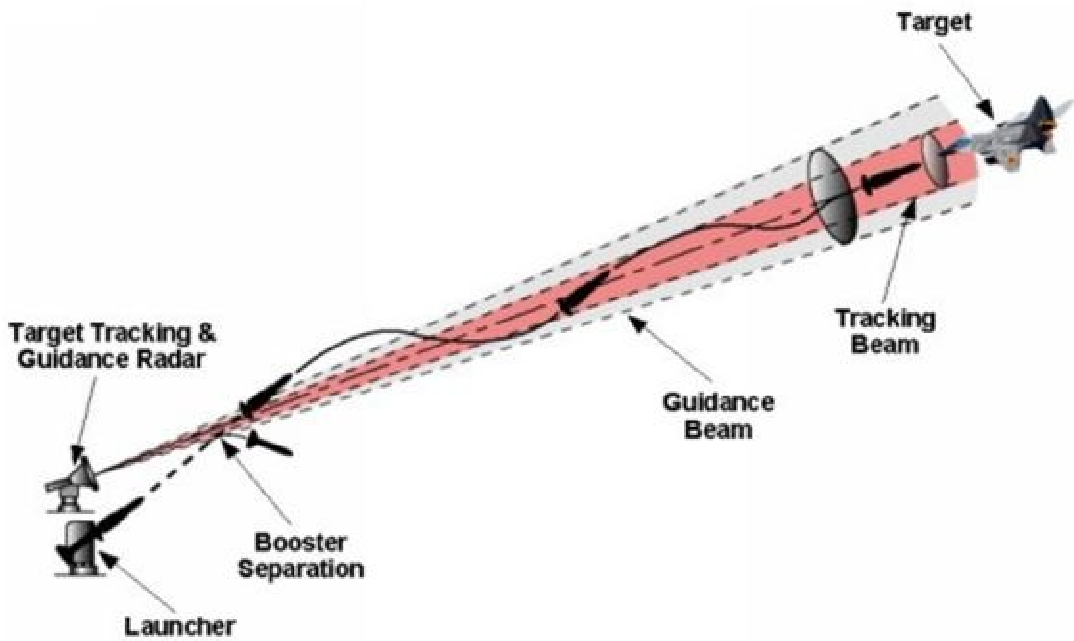


Figure 3-5: Beam riding geometry
(Source: US Naval Training Command Gunner's Mate Manual NAVTRA)

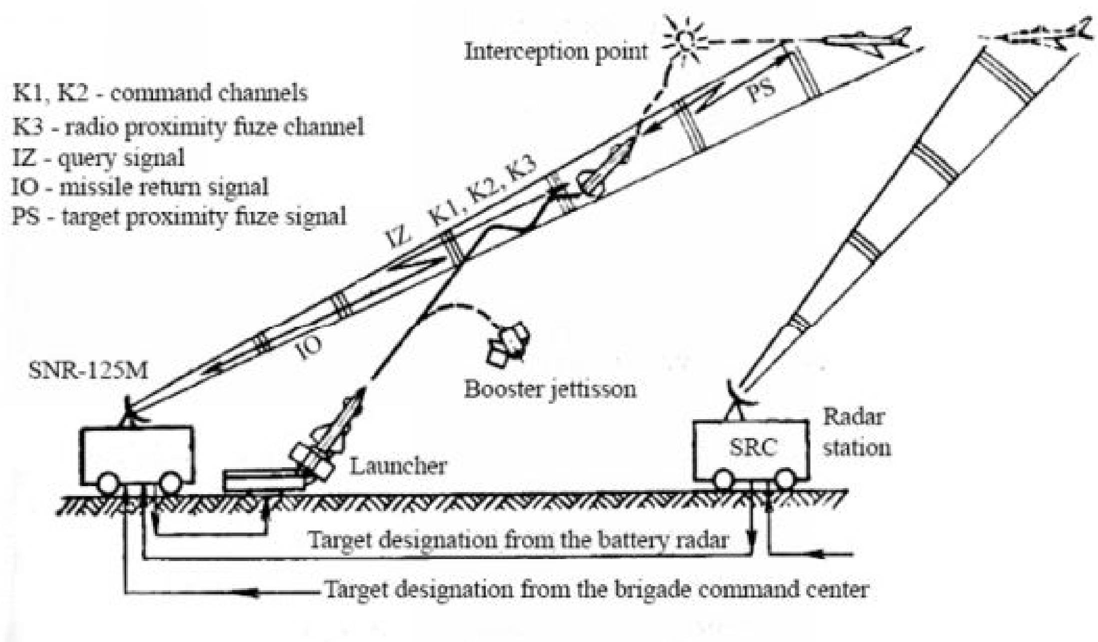


Figure 3-6: S-125 Beam riding geometry
(Source: S-125 system manual modified by authors)

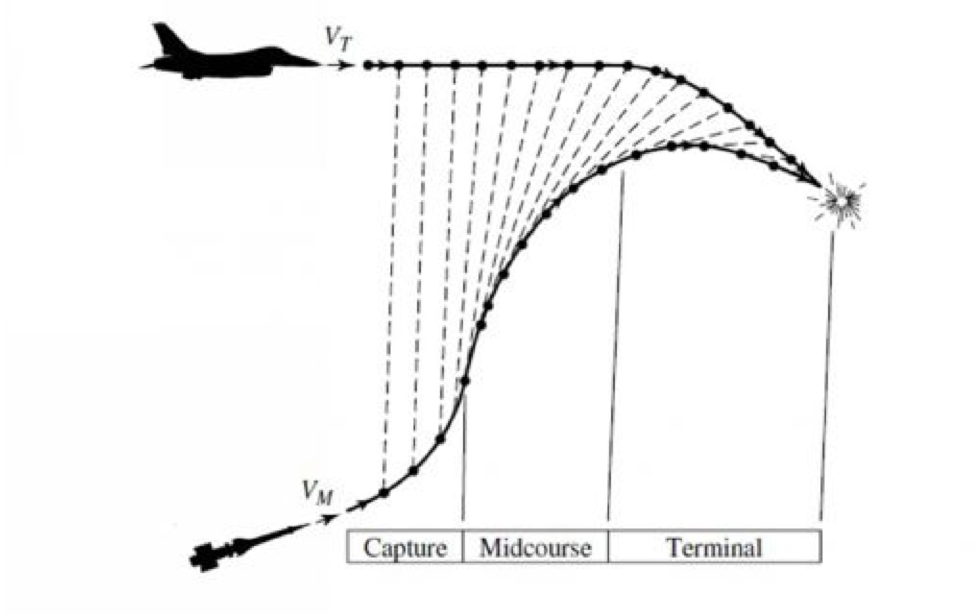


Figure 3-8: General pursuit guidance course
(Source: Missile Guidance and Control Systems modified by authors)

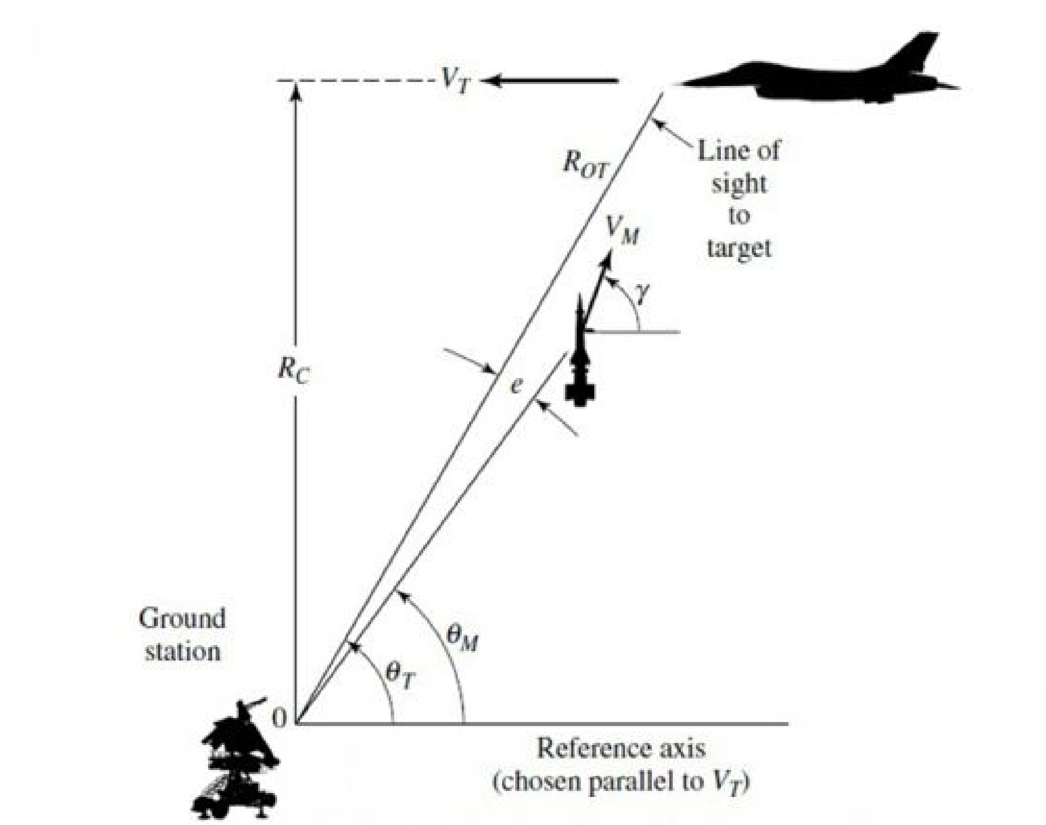
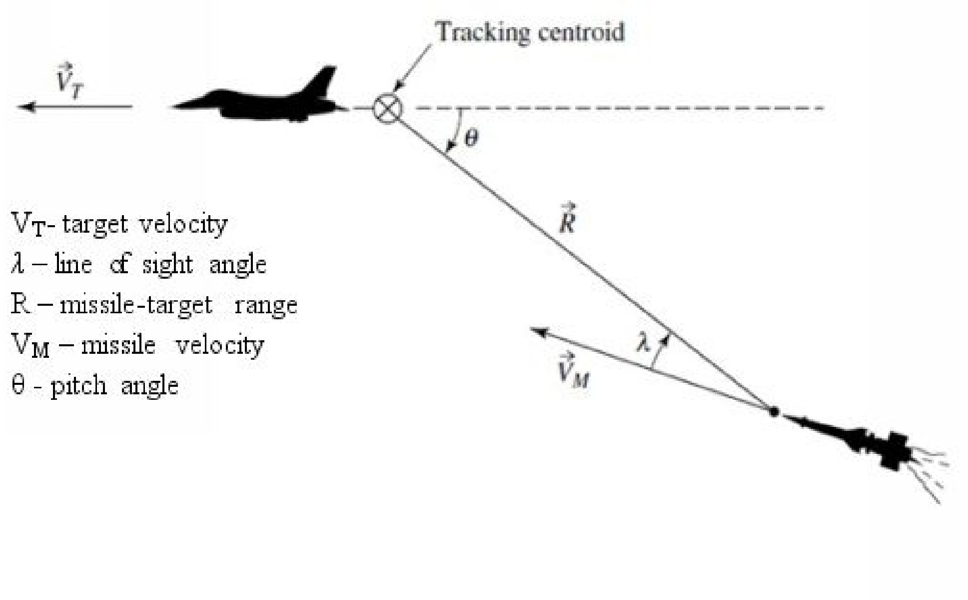
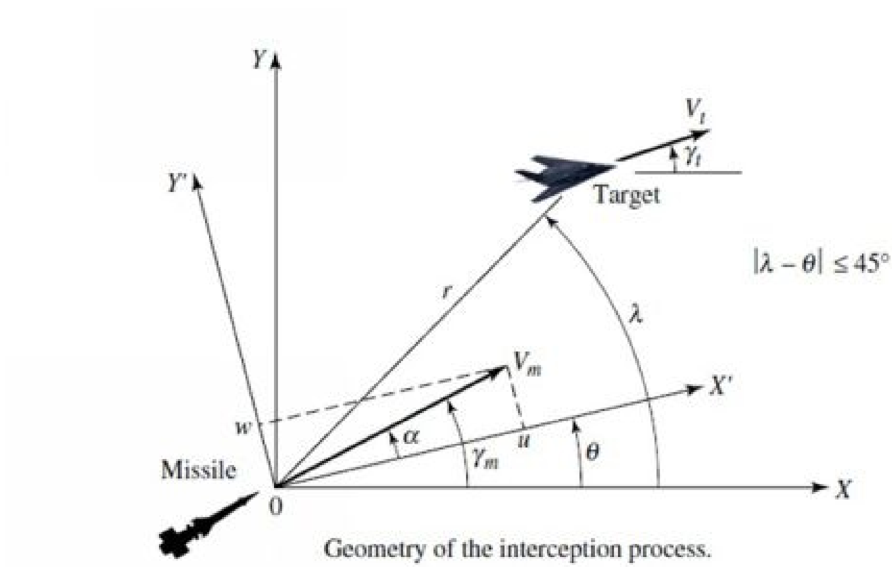


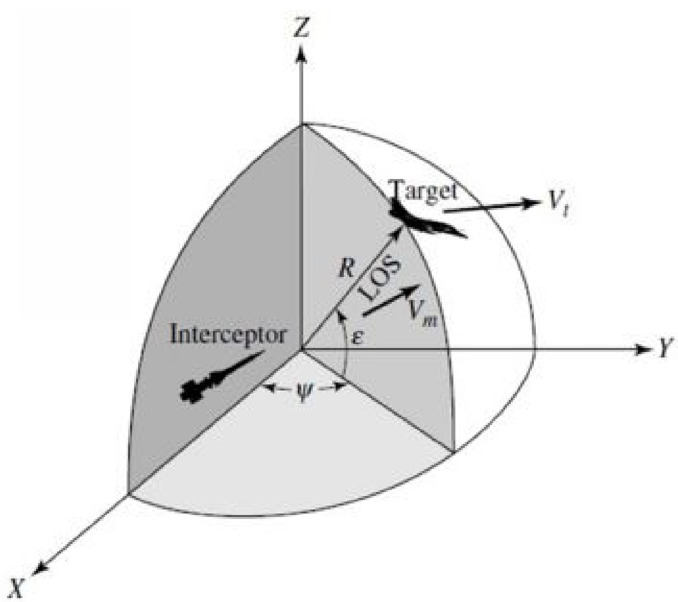
Figure 3-7: Geometric relationship for line of sight (LOS) command system
(Source: Missile Guidance and Control Systems modified by authors)

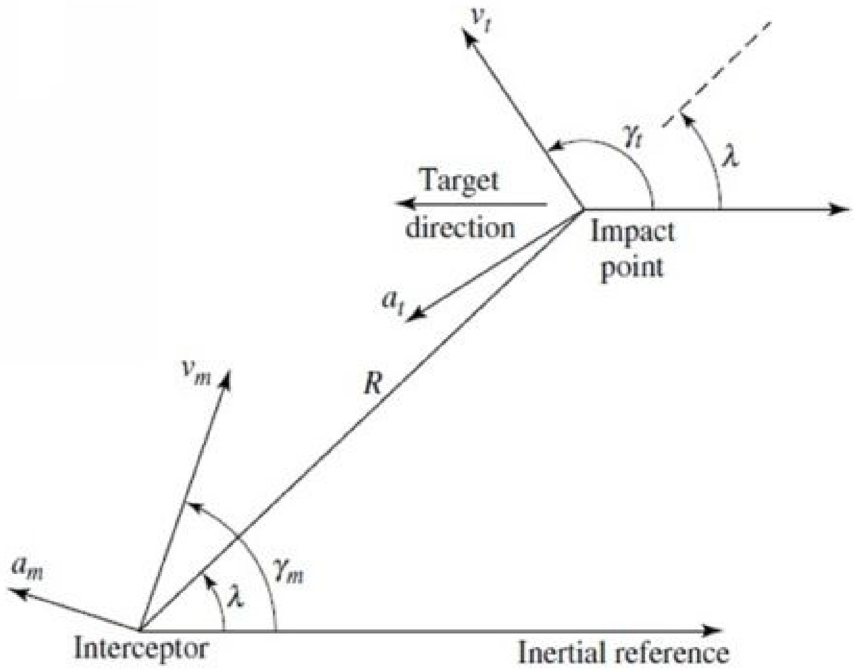




Geometry of the interception process.

Figure 3-12: Three-dimensional pursuit-evasion geometry
(Source: Missile Guidance and Control Systems modified by authors)





R = range between missile and target,
v_m = interceptor missile velocity,
v_t = target velocity,
λ = line-of-sight (LOS) angle,
γ_m = missile flight path (or heading) angle, that is, angle between the missile velocity vector and inertial reference,
γ_t= target flight path angle.

Figure 3-11: Geometry for derivation of proportional navigation
(Source: Missile Guidance and Control Systems modified by authors)

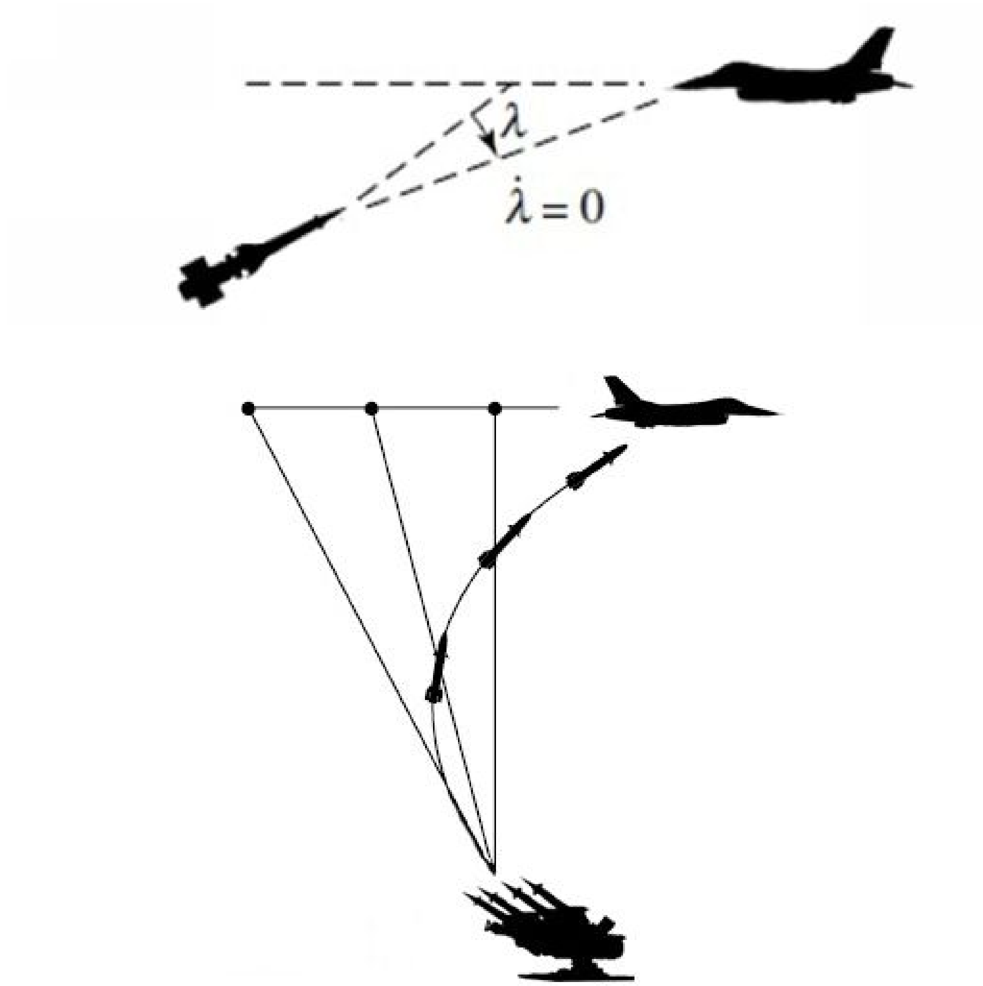


Figure 3-14: Three-point guidance method
(Source: Missile Guidance and Control Systems modified by authors)

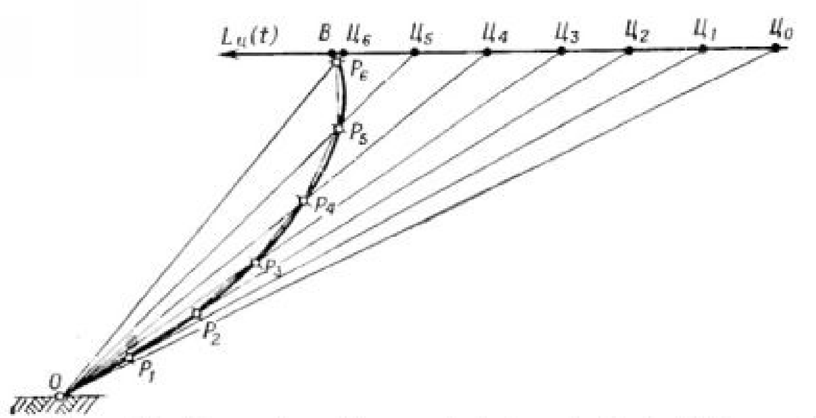


Figure 3-15: Three-point guidance method - from the Soviet S-125 manual

Chapter Four

Complex S-125 "Neva" (SA-3 Goa)

The S-125 Neva/Pechora / SA-3 Goa Surface to Air Missile system was developed to supplement the proven S-75 Dvina/SA-2 Guideline in Soviet and Warsaw Pact service. The S-75 Dvina/SA-2 Guideline was designed to provide medium to high altitude air defence coverage, primarily against bomber aircraft. As such it was not well suited to the engagement of low flying targets, especially fighter aircraft and cruise missiles. The design aim of the S-125 Neva/Pechora/SA-3 Goa was to produce a system with a low-to- medium altitude engagement envelope, providing protected airspace overlapping air defence coverage for all altitudes. Specifically, targets travelling at speeds of up to 1500 km/h (800 knts) and at altitudes from 100 m to 5000 m (~300 ft to 16,500 ft AGL), at ranges of up to 12 km (~6,5 NMI) were to be engaged and destroyed. Such performance is today characteristic of a point defence weapon, but during the 1950s it was more typical of area defence weapons.

The Soviets sought to build on the experience gained with the S-75 Dvina/SA-2 Guideline, using command link guidance and a proximity fused warhead, but recognized from the outset that a fundamentally new engagement radar design was required with much better clutter rejection performance than the workhorse RSNA/SNR-75/Fan Song series. The requirement for narrower antenna mainlobes droves the designers into the 9 GHz frequency band, well above the ~6 GHz operating range of the earlier RSNA/SNR-75 Fan Song series. Development was initiated in 1956.

The resulting weapon was more compact than the previous S-75 Dvina/SA-2 Guideline, permitting two rail launchers and use of a solid propellant sustainer, the first in air defence missile design. Canard controls were also employed. Like its predecessor, the missile used a solid rocket first stage booster. Numerous development problems were encountered throughout the system, especially with the performance of the radio proximity fuse and command link guidance at very low altitudes.

Trials of the V-600P missile and a new radar demonstrated the capability to engage targets at speeds of up to 2,000 km/h (~1,100 knts), at altitudes between 200 m and 10,000 m (~600 ft to 33.000 ft), with the target pulling up to 4G at 5,000 m to 7,000 m (16.600 ft to 23.000 ft) and up to 9 G below 3,300 ft at transonic speeds. Estimated single shot hit probability was 0.82-0.99%, deteriorating to 0.49-0.88% if chaffs were deployed.

While the new system met the needs of air defence branch, its stow and deploy times were similar to SA-2 Guideline and thus too great for the Army air defence units, who rejected the design, resulting in the development of the high mobility 2K12 Kub/SA-6 Gainful system. The S-125 Neva/SA-3A Goa achieved military acceptance in 1961 and was firstly deployed as part of the Moscow region SAM belt.

Complex SA-3 – is a single-channel by target and two-channel by missile air-defence missile system. The composition of its equipment allows engaging the targets in conditions of the enemy's extensive passive and active countermeasures. The complex is designed to engage strategic, tactical and naval aircraft, as well as air-based missiles in a wide range of conditions and use.

As in the previous SA-2, in the complexes of the SA-3 family, several types of target tracking methods are used:

1. "manual" by all coordinates;
2. "automatic by angular coordinates and hand-by-range;
3. "automatic" (by all coordinates).

In the case of electronic countermeasures and jamming, the "manual" mode by angular coordinates applies (with the guiding to the "center" of the source) with the setting of a distance mark on the far edge of the affected area. The missile radar guidance is conducted by signal of on-board radio transmitter only in automatic mode on all coordinates.

All equipment is mounted on the trailers, semi-trailers and on towed wheeled chassis which made it possible to deploy the complex into the full combat readiness in virtually any conditions. Typical deployment area for the battalion level may consist of 200 by 200 m square with low rise protection berms around.

The basic tactical unit is a battalion. In the Soviet classification called “divizion”. Missile components are assigned into the “battery”. Typical battery

composition is a single SNR-125 Low Blow series engagement radar, four dual rail 5P71 or four dual rail 5P73 launchers, and multiple PR-14 series dual round transporter/loader trucks carrying reserve missiles. Most SA-3 operators deploy the system at a fixed sites, with revetments using concreted pads and bays, and/or earthwork berms, to protect the missile system components. The basic SA-3 Goa qualifies as semi-mobile system, requiring several hours to deploy and set up combat position or to redeploy.

Prepared peacetime position for the SNR-125 missile guidance station (Stanitsa Navedenya Raket) is a semi-buried reinforced concrete structure or fully underground bunker, constructed with an additional dirt cover. This type of building provides additional facilities for the battalion command post, as well as a room for on duty combat crew as well as training classroom which can be also used use as a refuge for communication and power supply units stuff. The premises were equipped with a filtered and ventilated system. Additional protection against the chemical attack and gases are provided as well.

Missile launchers, at the prepared positions, are located in semi-ring embankments, usually with the concrete slabs with facing the battalion's designated responsibility sector. The launchers may be covered with the camouflage nets. Field conditions require a solid ground beneath the launchers and the gravel is often used (**Figure 4-1**).

To store the spare missiles, the N7 reinforced concrete structures was built and equipped with 8-16 missiles, which provided working space for the personnel of the preparation unit. On the roof of the structure, visual observation (PVN as per soviet abbreviation) was usually built, where the anti-aircraft machine guns or shoulder launched missile systems can be located. In special conditions, in example, in the absence of building materials or necessary sites, it was allowed to openly store a set of missiles in the packs of N1 at a battalion position.

The equipment of UNK is installed in the cabin, mounted on the semi-trailer OAZAZ-828 equipped with a filtration unit. In order to ensure acceptable conditions for conducting combat operations and carrying out combat duty on the unprepared position, the van may be equipped with air conditioning unit and electric space heaters.

This time is important to say that the potential opponent in most cases is

aware or prepared position and in the case of war, these prepared positions are the first one to be attacked (**Figure 4-2**).

SNR-125 “Low Blow” Fire Control and Engagement Radar

The main purpose of the S-125 air defence system, engagement of low and medium altitude targets, determined the construction requirements of the radar antenna system and the configuration of the antenna post UNV (**Figure 4-3**).

UV-10 antenna is used to search and illuminate the targets. During the target acquisition, pencil radar beams (3 cm wavelength narrow radar beams), scan the space in the sector 1-1.5 degrees by azimuth and 10 degrees by angle – vertically. Antenna is emitting a bundle of probing electromagnetic pulses from the transmitter and reflected signals from the aerial target are received for processing. The transmitter/receiver switch provided protection of the receiver from the powerful signal of the transmitter over time interval of its operation. Antenna is controlled from the UNK cabin and it can scan by azimuth without restrictions and by the elevation from -5 degrees, to +79 deg. It is possible to search for targets practically in the entire upper hemisphere. When conducting autonomous combat operations, automatic aerial target searching modes is provided:

- radial survey (Krugovoi Obzor) - rotation of the antenna post to 360 degrees, in 20 seconds;
- small sector search (Malii Sektornii Poisk) - scan sector of 5-7 degrees, by azimuth with a change in manual mode, the position of the antennas in the elevation angle;
- large sector search (Bolshoi Sektornii Poisk) - scan sector of 20 degrees, by azimuth with the possibility of adjusting the amplitude of the azimuth change to the small sector search mode.

When working on the brigade level (directing by the brigade command and control post), the search for targets is performed in the designated sectors. Depending on the complexity of the aerial situation, the tracking is in automatic or manual mode. When the target is detected, UV-10 antenna scanning stops; the mechanical scanner stops, and the antenna is used only to determine the range to the target (the transmission is formed not by a bundle of probing signals, but by a continuous series of pulses). UV-11 wide beam receiver antenna with 3 cm wavelength, is mounted in the angled configuration, receives the signals on two

different angles – F1 and F2. Illumination of UV-11 receiver antennas in two angled planes with 1-degree x 10-degree made possible for missile to lock and to be guided into the target.

UV-12, decimeter wavelength, missile command transmitter antenna with a wide beam is used to transmit control commands to the missile (**Figure 4-4**).

The base for the UNV antennal post is the artillery platform KZU-16K. When deployed to the combat position the complete post rests on the hydraulic jacks. The total height of the antenna post in the combat position is around 6.5 m.

For antenna post transportation, the trailer 2-PN-6M is used. During the transport, the complete antenna assembly is folded. The spare parts for both the UNK and UNV are located in a mobile repair shop (**Figure 4-5**).

Other Equipment

The transportable launcher 5P71 (SM-78A-1) on earlier versions is two-beam missile launcher and later modified and modernized as a four-beam missile launcher (PU - Puskovoia Ustanovka) with a variable start angle and is equipped with a synchronous-servo electric drive for positioning by the azimuth and elevation in any given direction. The calculated mass of missiles placed on the launcher could reach 945 kg. When deployed at the starting position with an allowable slope of the site to 2 degrees, the horizontal alignment of the launcher is made with the help of screw jacks.

The transporter and loading machine PR-14A (later the modifications of the PR-14AM, PR-14B) were based and developed on ZIL-157 universal truck chassis. Coupling along the launcher guiding beams was achieved through ground access driveways, as well as using stoppers on the transport-loading machine and launcher. The normative time for the transfer of the missile from the transporter to the launching platform is 45 s.

5V24 and 5V27 surface-to-air guided missiles

The 5V24 (V-600P) missile is a two-stage solid fuel guided rocket (**Figure 4-6**). The first stage of the rocket is a booster with a solid propellant engine, PRD-36 (military designation – 5S45), developed in KB-2 of the plant N81 under the leadership of II. Kartukov. The PRD-36 is equipped with 14 single-channel cylindrical gunpowder pens, type NMF-3K, with a diameter of 134 mm and a length of 1180 mm. The total mass of the engine charge, which received the index 5B84, is 280-281 kg. The maximum operating time for the booster is 4 s. The booster is equipped with an igniter 5B94. The nozzle of the starting engine is equipped with a "pear", which allowed regulating the area of the critical section depending on the ambient temperature. Each console of the rectangular fin stabilizer is fixed with a hinge on the front frame of the tail section. During ground operation, the longer side of the stabilizer adjoins the cylindrical surface of the starting motor housing.

During the blast off, the screed which secures the stabilizer arms, is cut with a special knife under the action of inertial forces and the fins turns more than 90 degrees, adjoining the outer surface of the tail section of the booster in the form of a cone. The slowdown of the stabilizer's console before contact with the surface of the tail section is provided by the use of a brake piston device, as well as a collapsible pin fixed to the stabilizer console. The extreme rear flight position of the consoles provided a high degree of static stability of the spent launch vehicle after separation from the marching stage, which led to an undesirable expansion of the dangerous zone of the fall of the starting stage. Therefore, in subsequent versions of the missile, measures were taken to eliminate this shortcoming.

The 5V24 surface-to-air missile was adopted for service in 1962. It was designed primarily to engage different air targets, chiefly strategic and tactical aircraft, used in a wide range of operational environments. It was Soviet first missile equipped with only solid-propellant rocket motors. This missile incorporates a range of unique design and technological solutions, including the stabilizing fins, which unfold after the missile is fired (the stabilizing fins are fitted on the booster) and the spring mechanisms of steering devices providing

for the required efficiency of aerodynamic control surfaces in a wide range of flight altitudes and speeds.

In the 1960s and 1970s, a few derivatives of the 5V24 SAM were developed, including the 5V27, 5V270, etc., which were much more effective than the basic version. The 5V24 and 5V27 SAMs are two-stage rockets featuring canard configuration. The missile is fired from an inclined position. Its launcher is aimed in azimuth and elevation. In flight, the missile is controlled and guided toward the target via radio commands sent by a ground-based (shipborne) guidance station. The warhead is activated at a certain distance from the target by a command generated by the electronic fuse or sent by the ground-based guidance station. The first stage of the 5V24 SAM is essentially a solid-fuel booster fitted with four stabilizing fins, which unfold after the missile is launched, and two braking surfaces (fitted to later models) designed to shorten the booster flight path after separation. Physically, the sustainer stages of the 5V24 and 5V27 SAMs consist of compartments containing the electronic fuse, control surface actuators, a HE fragmentation warhead, airborne equipment, a solid–propellant rocket motor and the control command receivers (**Figure 4-7**).

The SAM's flight control system elements include four aerodynamic control surfaces located in the tail section of the sustainers and the ailerons fitted to the sustainers wings. The ailerons are used in the launch phase.

The response time of the missile self-destruction device is set to 26 seconds after the launch, after which the missile was destroyed if not detonated before in the vicinity of the target. The length of the V-600P missile is 6.09 m, the starting mass - 912 kg. The diameter of the hull of the flight stage is 0.375 m, the diameter of the booster is 0.55 m.

The S-125 surveillance radar stations P-12 (P-12NM) or P-15 Trail (Flat Face - according to NATO codification) are equipped with autonomous diesel power stations for the installation of antennas on the automobile chassis. To increase the range of targets detection at low altitudes, the P-15 station is equipped with an additional antenna on the mast device "Unzha" (P-15 with antenna placement on the mast device (Squat Eye) (**Figure 4-8**).

The complex used ground-based radio friend/foe checker "Silicon-2M" and "Password-1". Usually in combat positions at the prepared locations, the hardware vans and diesel-electric power stations of the surveillance radar

stations are located in concrete engineered structures.

For the training purpose of the missile operators, as well as the guidance officers, combat simulator “Accord” is assigned to the S-75 and S-125 systems, typically of one set for four battalions. The combat simulator is placed in the semi-trailer OdAZ-828.

In the course of serial production, the equipment has been constantly improved, the production process developed, new materials introduced, and technologies developed to ensure the reliability of the components.

ZRK S-125M "Neva-M"

During the tests of the S-125 system, a number of shortcomings of the 5E15 radio detonator appeared. In addition, the zone of damage already seemed clearly insufficient for a two-stage SAM with a mass of almost a ton. This was evident in comparison with the new missile system developed for the army, 3M9 "Kub", which development started in 1958.

On March 31, 1961, before the full adoption of the S-125 system into the service, a decision has been made by the military-industrial complex to modernize the missile and hardware of the SNR-125 (**Figure 4-9**). It was based on the proposals for the modification of a missile that will increase the range and the upper limit of the target destruction zone, with an average speed increased to 630 m/s. It was suggested that the launcher be thoroughly altered, ensuring that four missiles were placed on it. According to one of the versions, the last task was put personally by D.F. Ustinov, soviet defence minister at that time.

The work on the new B-601P (5V27) missile was officially launched June 1961. The main directions of work were the development of a new radio-detonator 5E18 and a propulsion engine on a fundamentally new blended fuel. The high specific impulse and increased density of this fuel, while maintaining the dimensions of the rocket, had to increase the engine's power characteristics (**Figure 4-10**).

During the B-601P factory tests, conducted from August 1962, total of 28 launches were carried out, including six missiles in combat configuration, with which two MiG-17 targets were shot down. At the end of 1962, joint tests began, the course of which was delayed somewhat due to the unreliability of the engine at temperatures at the lower temperatures. At lower temperatures, the engine was

systematically destroyed (one in five at -30° C and five of 17 at -40° C).

The main difference between the new missile and the previously created V-600P missile is the new, more advanced propulsion motor, new 5E18 fuse, new 5B79 safety-action mechanism and a 72 kg fragmentation 5B18 warhead with 4500 fragments with a mass of 4.72-4.79 g.

Externally, the V-601P missile were easily identified by two aerodynamic surfaces that were installed on the transitional connecting compartment behind the upper right and lower left consoles in order to reduce the range of the launch vehicle after its separation. After separating the stages, these surfaces unfolded, which led to an intensive rotation and braking of the accelerator with the destruction of all or several stabilizer arms and, as a result, to its erratic fall at a relatively small distance from the launcher.

The operating time of the booster is 2-4 s, the propulsion engine - up to 20 s. To expand the zone of damage, the missile was also guided on the passive part of the trajectory, while the self-destructing time was increased to 49 seconds. The missile could maneuver with overloads of up to 6 g. The missile has been designed to operate in the temperature range from -40 degrees to +50 degree. Simultaneously with the adoption of the V-601P missile, the Government requested enhancement of the combat capabilities of the complex, in particular, to provide engaging the aerial targets flying at speeds of up to 2500 km / h, ensuring the defeat at altitudes of up to 18 km and to increase protection against electronic countermeasures. The necessary measures were carried out quite quickly, but officially the main characteristics were corrected only after three years.

The V-601 missiles of all modifications were manufactured by the Kirov plant N32. It was supposed to organize the production of missiles at the Leningrad plant N272, but this enterprise was switched to the production of missiles for the S-200 complex.

The transportable four-beam launcher 5P73 (SM-106 in the designation system TsKB-34) was designed under the supervision of the chief designer B.S. Korobov (**Figure 4-11**). Without gas reflectors and running gear, it was transported by YAAZ-214 truck. In order to prevent the missile from touching the ground or local objects while "settling" in the initial uncontrolled stage of the flight, when shooting at low altitude targets, the minimum angle of the missile's

collision prevention was set at 9 degrees. To prevent erosion of soil during rocket launches around the platform, a special rubber-metal multi-section circular coating was applied.

The charging of the launcher with the missiles has been carried out in succession by two TZMs missile transporters which approached the right or left pair of beams (**Figure 4-12**). It was allowed to load the launcher simultaneously with the V-600P and V-601P missiles of early modifications. To provide the guides to the PR-14M (PR-14MA) transport vehicles, access routes were installed to the fixed position of the TZM relative to the left or right pair of PU beams (**Figure 4-13**).

The launcher was produced by several plants, including the plant in Yurga (since 1977). When the battalion is located at the prepared position, the necessary electric power has been provided from a mobile transformer substation (TPS), mounted on the body of an axial trailer.

To provide target designation in the conduct of combat operations without ACS, S-125 battalion has assigned surveillance radar: a meter range-type P-12 (P-18) and decimeter range P-15. The surveillance radar stations P-12NM (P-18) (**Figure 4-14**) and P-15 were equipped with own autonomous power supplies AD-10-T/ 230MAB-8-O/230M and AB-4-T/230M. To improve the detection capabilities of low-altitude targets, SRC P-15 was attached to a jack-up antenna-mast device "Unzha" to lift the antenna to a height of up to 50 m. Determination of “friend-or-foe” was made by the ground-based radar interrogators (NRZ) "Password-3P" (75E6)) or "Password-4P" (1L22). The S-125M complex as was adopted on September 27, 1970.

SAM system S-125M1 (S-125M1A) "Neva-M1"

In the early 1970's. The S-125M complex was upgraded in terms of improving the electronic countermeasure equipment, and missile control channels. With the introduction of the television-optical sighting equipment (TOV) and the Karat-2 target (9S33A), it was possible, under conditions of visual observation of the target, to guide it and fire without the engagement of the fire control radar. In this case, the transmitter of the target channel switched to the equivalent of the antenna placed on the antenna post. The target electronic countermeasures under the visual observation conditions have been greatly reduced. However, the optical sighting loose its effectiveness in the conditions of

bad weather and cloudiness, as well as when the television screens are illuminated when pointing in the direction of the sun or on the pulsed light source set by the attacking aircraft. In addition, the television-optical sight did not provide information about the range to the target, which limited the choice of guidance methods and significantly reduced the efficiency of firing at high-speed targets.

In the second half of 1970s, the new equipment was introduced to increase the effectiveness of engaging the targets at the low altitude as well as the engagement of the surface detected targets. In the second case, the system can perform as surface-to-surface system. In addition, a new modification of the 5V27D missile with increased flight speed was introduced, which allowed the engagement of the targets both in approach and in chase. The length of the missile increased, the starting mass increased to 980 kg with the mass of the booster of 407 kg. For heavier 5V27D, it was possible to load only three missiles on the 5P73 launcher when placed on any beams.

The S-125M1 SAM with the 5V27D missile was adopted in May 1978. Since the early 1980's and the increase of use of anti-radiation missiles, S-125 systems of all modifications has been upgraded with the equipment to “attract” the anti-radar missiles and the new equipment designated as a "Dubler" has been installed with one or two remote simulators of the fire control radar emission (imitator) and located at the proximity of the battalion firing position. Export option for the S-125 Neva has been designated as a “Pechora” and were supplied to many countries and used in a number of armed conflicts and local wars (**Figure 4-15**, **Figure 4-16**). The complex in the "tropical" version was painted with the special coatings which repel termites.

The "Pechora"

The export version of S-125 “Neva” designated as “Pechora” which, according to experts from all over the world, belongs to the best models of air defence weapons systems, was delivered to 35 countries. According to foreign data, the S-125 complexes are in service with Algeria, Angola, Afghanistan, Bulgaria, Bosnia, Hungary, Vietnam, Egypt, India, Iraq, Yemen, DPRK, Cuba, Libya, Mali, Mozambique, Mongolia, Peru, Poland, Syria, Tanzania, Finland, the Czech Republic, Ethiopia, Serbia and almost all CIS countries. In just twenty years, approximately 523 complexes were delivered, a large part of which, after several decades of exploitation, has not exhausted its resource and is capable of

remaining ineffective service well into the 21st century.

New technological development provides the possibilities that with upgrades the combat effectiveness of the system can be increased many times at significantly lower costs than purchase of new systems with the comparable characteristics. Therefore, in recent years, several options for upgrading the complex have been proposed and one is Pechora M.

Pechora-2A upgraded surface-to-air missile system

The purpose of the Pechora-2A upgraded surface-to-air missile (SAM) system is to defend vital administrative, industrial and military installations against air attack weapons with radar cross section (RCS) more than 0.2 m^2 and speed up to 700 m/s. The export versions of the system designated the Pechora, Pechora-M and Pechora-M1A were deployed with some countries around the world. In 1998 – 2001, the Almaz Research and Production Association (R&PA) developed a new modernization package for the Pechora-2A SAM system, which is offered to foreign users. The specific objectives of this modernization package include (**Figure 4-17**):

-extension of system service life by replacing the analog signal processors, target and missile coordinates measuring devices, guidance control command generator devices, crew training equipment, etc., with up-to-date digital equipment;

-enhancement of tactical and technical character tics by introducing digital algorithms in information processing and misguidance and control elements;

- improvement of system operation and maintenance procedures.

The Pechora-2A SAM system comprises:

- upgraded missile guidance station SNR-125M-2A
- upgraded command and control equipment van UNK- M2A;
- antenna station UNV; maintenance vehicle PRM;
- missile battery, including up to four launchers 5P7 and eight reload vehicle PR-14AM;
- power generating system
- maintenance facilities;
- surface-to-air guide missiles 5V270.

Surveillance and target designation radars P-12 and P-15 can additionally be

attached to the SAM system. The operation of the SAM system is controlled from the equipment van. The air situation data supplied by either of the above radars are displayed on a remote indicator.

After the target has been selected, the station is turned in azimuth toward it and it azimuth and elevation are measured again. Then, tracking of the acquired target in azimuth, elevation and altitude is assumed. The operator tracks the target either automatically or manually. A combined tracking mode is also available. If the target tracking channel is affected by passive noise and/or by clutter, a moving target indication (MTI) mode is switched on. In the event of active noise, a coherent pulse accumulation mode is engaged. More to that, a TV channel is used, which enables the operator to track the target in its angular coordinates manually or automatically. The Pechora-2A SAM system has one target channel and two missile channels. Two missiles can attack the target simultaneously. When fired, the missiles are located on their launcher in the inclined position. The launcher is coupled with the missile guidance radar via synchronous power drives. In flight, the missile is controlled and guided toward the target by radio commands coming from the missile guidance radar. The missile's warhead is detonated either by a command generated by an electronic fuse when the distance to the target permits its activation or by a command generated by the guidance radar when air targets flying below 50 m are being attacked.

All equipment of the Pechora-2A SAM system is carried on trailers and semi-trailers. Power is supplied from mobile diesel driven electric generating sets or from industrial power lines.

The Pechora-2A is an all-weather SAM system capable of being operated in different climatic conditions. The design documentation developed to upgrade the Pechora-2A system includes its enhancement with versatile digital devices, which embody technical solutions realized in the S-300PMU1 SAM system. Modernization of the Pechora SAM system includes replacement of 46 analog units with three new units incorporating up-to date technology and components. Moreover, three additional digital units are introduced to perform new functions, such as resistance to jamming, automatic tracking in the TV channel and antenna control. As regards maintenance operations, there will be a decrease by more than a factor of 2 - 2.5 in the time it will take maintenance personnel to carry them out on the system. Energy consumption will tall by 20 to 35 percent. The degree of commonality between the equipment items used to upgrade the

Pechora SAM system to the level of Pechora-2A and those used to upgrade the Volga SAM system is 90 percent.

The modernization package envisages conduct of preventive maintenance operations on the system in accordance with the program and methods of assessment of the status of the dismounted analog equipment. This work will be carried out at user's location. The scope of modernization can be changed to meet customer requirements.

According to the Almaz R&PA, developer of the Pechora SAM system, the modernization package offered to the operators of this system fully meets cost effectiveness criteria.

Pechora-2M and ML upgraded surface-to-air missile system

Compared with the original version, the upgraded Pechora-M missile system have expanded range, increased efficiency, better resistance to jamming, better mobility and improved performance. Analog equipment during the upgrade is partially replaced by digital equipment; automated rocket launching process, an indication of the guaranteed zone of destruction of airborne air defence systems was introduced. For the increase of mobility, missile launchers are mounted on the chassis of off-road vehicles, such as ZIL-131. The normative time for the combat deployment has been reduced to about 100 minutes (**Figure 4-20, Figure 4-21, Figure 4-22**).

The main purpose of the upgrades introduced into the Pechora-2M surface-to-air missile (SAM) system is:

- extension of lifetime by replacing obsolete components with up-to-date ones;
- enhancement of tactical characteristics by expanding the system's target engagement envelope to counter modern air threats in the face of standard and highly sophisticated countermeasures;
- reduction of the scope and time of maintenance operations carried out on the SAM system equipment.

The SAM system upgrade includes:

- enhancement of its immunity to active and passive noise;
- introduction of a new tele-optical system for target acquisition and automatic tracking in the passive mode by day and night via a laser rangefinder;

- expansion of the system's target engagement envelope by introducing sophisticated digital devices designed to measure and generate target coordinates in order to enhance target tracking accuracy;
- enhancement of the system's ability to detect and track small and low-flying targets;
-introduction of new workstations for the guidance and launch operators outfitted with advanced equipment based on up-to-date components. The operator displays present information coming over radio and optical channels. It includes target dynamic parameters, target type, engagement zone, status of missile launchers and other important information;
- introduction of a built-in trainer for the training of SAM system operators;
- built in automatic testing facility providing information down to a defective element (cell, module); - replacement of basic equipment with up-to-date devices built from up-to-date components and embodying the latest technology. In the command and control van (UNK), 100 percent of equipment will be changed, in the antenna station (UNV) – 80 percent and in the launcher - 80 percent;
- reduction of the nomenclature of spare parts by a factor of 8 to 10.

There are two basic versions of the upgraded system:
- containerized version with organic transportation facilities available for the launcher and antenna station and with autonomous power generating facilities;
- mobile version with the launcher, antenna station and the command and control van mounted on a truck chassis. Autonomous power generating facilities are available. Modernization of the command and control van involves replacement of all of its electronics namely: up-to-date information reception, processing and presentation devices, as well as equipment testing, crew training and data recording devices based on modem computing technology are installed.

The new equipment includes: automated workstations for the commander, guidance operator and launch operator; a guidance and control computer; information exchange devices; parameter recording devices; a trainer, etc. The equipment is installed in a new van mounted on a truck chassis. The van can be provided with lifting facilities for placement on the chassis or removal from the chassis for placement on the ground.

Modernization of the antenna station (UNV) involves the removal of

receiving and tele-optical sighting devices and the introduction of new equipment based on up-to-date computing gear and solid-state device technology. The new equipment includes:

1. the receiving devices (the RF portion and main amplifiers);
2. counter – counter-measures devices;
3. digital moving target indication (MTl) system;
4. control command generation device; coordinate systems;
5. synchronizer; a guidance and control computer, power supplies, etc.

Moreover, a new control command transmitter improved tele-optical sighting device, laser rangefinder, antenna drive control elements and information exchange devices linked with the command and control van are installed. The antenna station (UNV-2) is mounted on a truck chassis. It is provided with autonomous power supply sources and automatic leveling facilities. To lower and elevate the antenna, a hydraulic system has been introduced. The antenna system mounts the antennas of noise suppressors and of the satellite navigation system.

Modernization of the launcher involves the introduction of a highly reliable monitoring system, launch control system, drive control system, and information exchange (with equipment van UNK-2) system. The launcher is mounted on a truck chassis and is provided with autonomous sources of power, a satellite navigation system and an automatic leveling system. The launcher is reloaded with missiles from a new or upgraded reloading vehicle PR-14-2M.

Modernization of surface-to-air missile 5V27D (**Figure 4-17**, **Figure 4-18**) involves upgrades to the first-stage rocket motor, warhead and electronic fuse to increase the slant range of the missile's target engagement envelope to 32 km and to raise target hit probability. In dealing with low flying targets, the altitude of normal operation of the electronic fuse has decreased from 60 to 20 m. Warhead lethality has grown as the total weight of bomblets is 1.6 times and the number splinters is 3.7 times those of the previous warhead model.

Figure 4-2: SNR-125M, with UNV and UNK vans and power generation van (Source: Vestnik PVO)

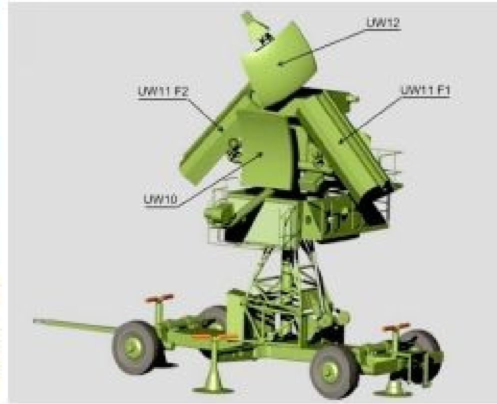


Figure 4-3:SNR-125 antennas

Figure 4-1: Typical SA-3 site deployment
(Source: ausiarpower.com via http://peters-ada.de)

Figure 4-5: SNR-125 and 5P71 launcher (Source: Wikipedia)

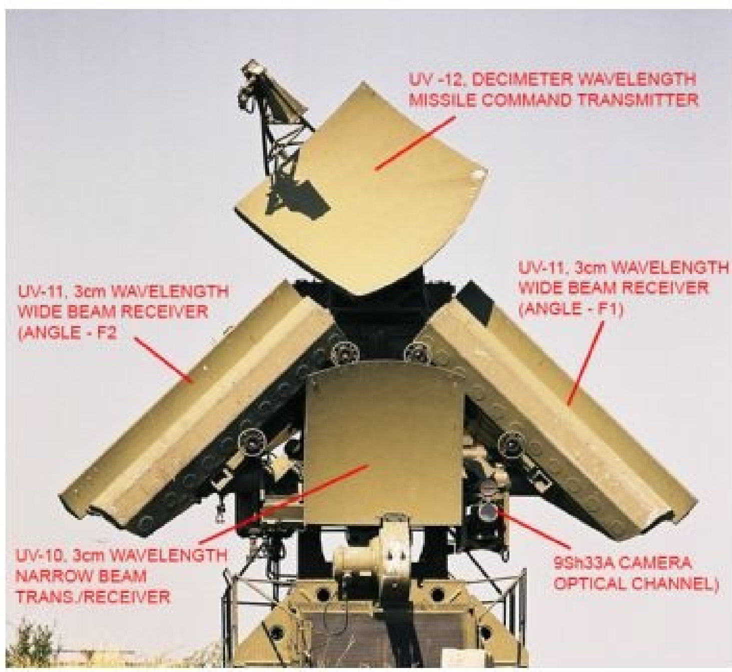
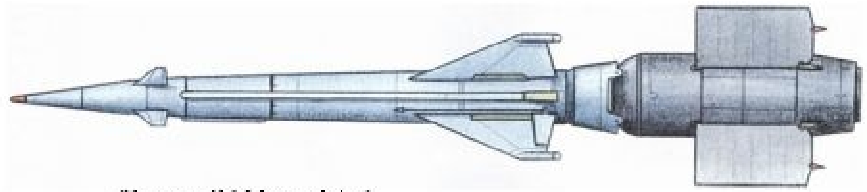
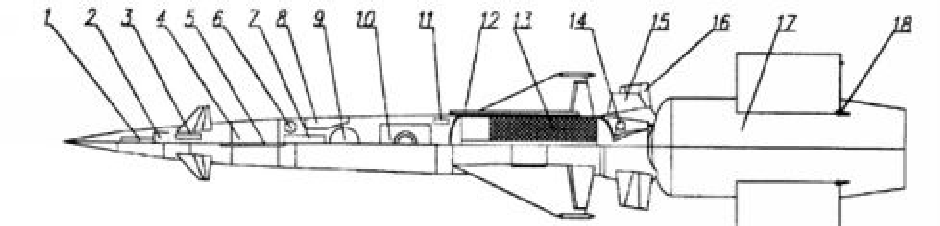


Figure 4-4: SNR-125 antennas with frequencies bands (Source Miroslav Gyurosi)



(Source: SAM simulator)



1. Proximity fuse transmit antenna
2. 5E18 radio proximity fuse
3. Canard controls
4. 5P18 72 kg fragmentation warhead (4,500 fragments)
5. Receive antenna
6. Transducer
7. Splitter/converter box
8. Battery
9. 5A22/APS-600 autopilot
10. 5U42/UR-20A Command link control module
11. Aileron control
12. Aileron drive
13. Sustainer powerplant with 151 kg of 301-K solid propellant providing 20 sec burn duration
14. Compressed air tank
15. Initiator for sustainer powerplant
16. Adaptor destabilising fins
17. 5S45/PRD-36 boost powerplant with 2-4 sec burn duration / 14 tubes of NMF-3K propellant

Figure 4-7: 5V27 (V-601P) Goa Cutaway (via Vestnik-PVO/Aviatsiya i Kosmonavtika)

Figure 4-8:P-15 radar
(Source: SAM simulator)

Figure 4-11: 5V27 missile on 5P73 launcher (Source: authors)

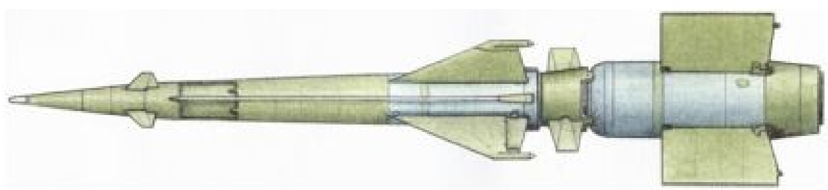


Figure 4-10: 5V27 missile (Source: SAM simulator)

S-125M Battery Components			
System	Qty	Function/Composition	Vehicle
SNR-125 UNV Cabin / Low Blow	1	Radar head van	Towed
SNR-125 UNK Cabin	1	Radar operator van (OdAZ-828 semitrailer)	Towed
5E96 Cabin	1	Power generator van	Towed
5P71 / 5P73	4	Launcher, Two/Four Rail	Towed
PR-14A/AM	8	Transporter/transloader	ZIL-131
AKKORD	1	Training Emulator (OdAZ-828 semitrailer)	Towed
P-15M Squat Eye	1	UHF-Band Low Level Acquisition Radar	Ural-375
P-15/19 Flat Face	1	UHF-Band Acquisition Radar	Ural-375
1L22 Parol 4 / 75E6 Parol 3	1	IFF Interrogator	KrAZ-255
PRV-10 Konus / PRV-11 Vershina / Side Net	1	Heightfinding Radars	Towed
5F20/5Ya61/62/63 Tsikloida	1	Radio relay van (OdAZ-828 semitrailer)	Towed

S-125 Optional Battery Components			
RD-75 Amazonka	1	Rangefinding radar	Towed
P-12M/P-18 Spoon Rest	1	VHF-Band Acquisition Radar	Ural-375
AT-S	N	Tow Tractor	-

Figure 4-9: S-125 battery components (Source: ausairpower.com)

Figure 4-14: Modernized P-18 surveillance radar (Source: Wikipedia)

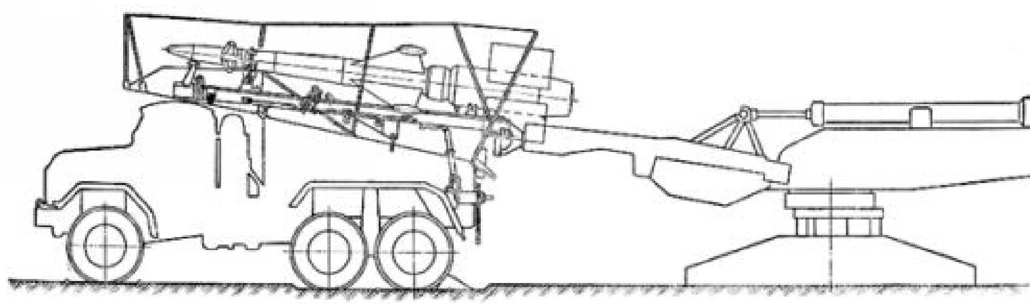


Figure 4-13: PR-14A/AM transporter and 5P73 launcher (Source: S-125M1 manual)

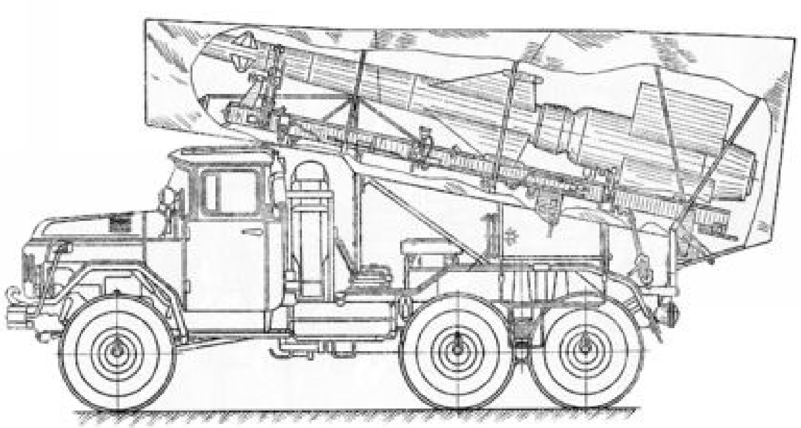


Figure 4-12:PR-14A/AM transporter (Source: S-125M1 manual)

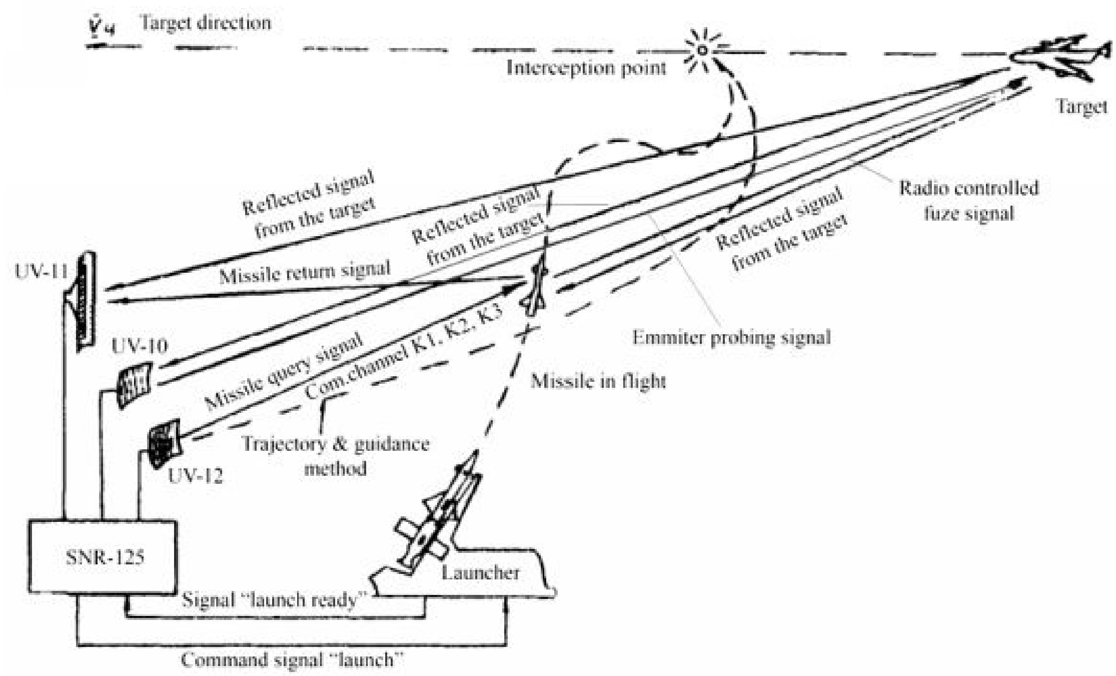
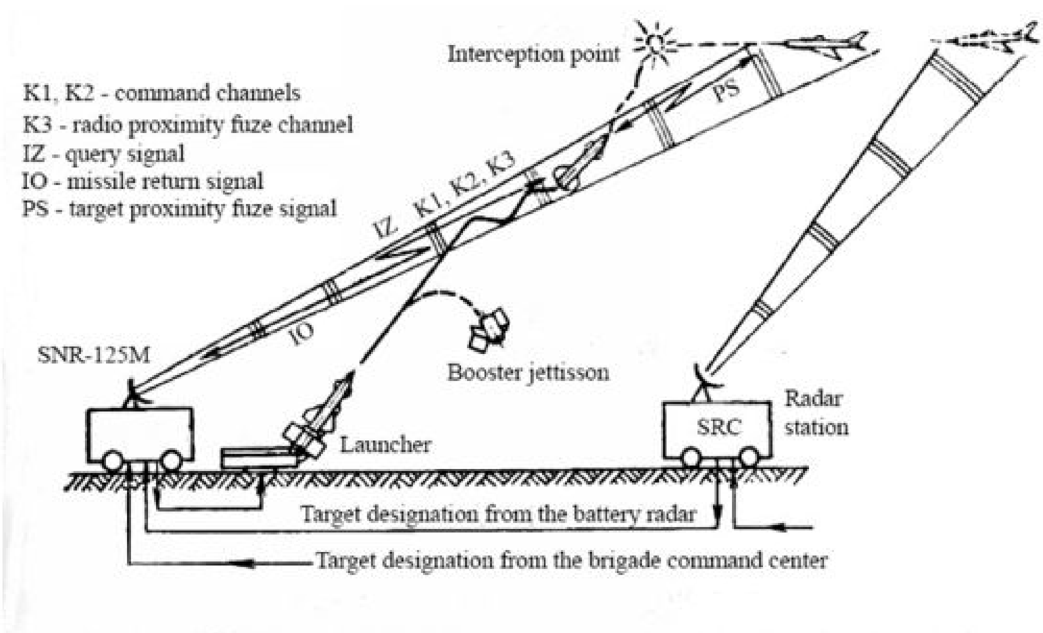


Figure 4-16: SNR-125 guidance diagram (Source: S-125M1 manual, authors modification)



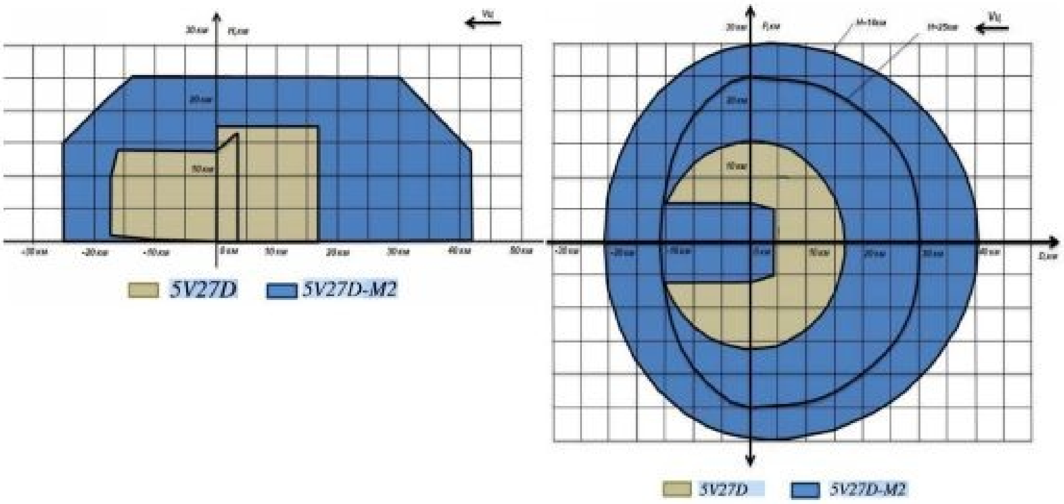


Figure 4-18: 5V27D and 5V27D-M2 envelope comparison
(Source: ausairpower.com)

Figure 4-17: Pechora 2M digitalized workstation in fire control center. One of the authors sitting left. (Source: authors)

Figure 4-19: 5V27D Launching sequences comparison (Source: authors)

Figure 4-20: Venezuelan Pechora 2M (Source: Wikipedia)

Figure 4-21: Egyptian Pechora launcher (Source: Egyptian TV)

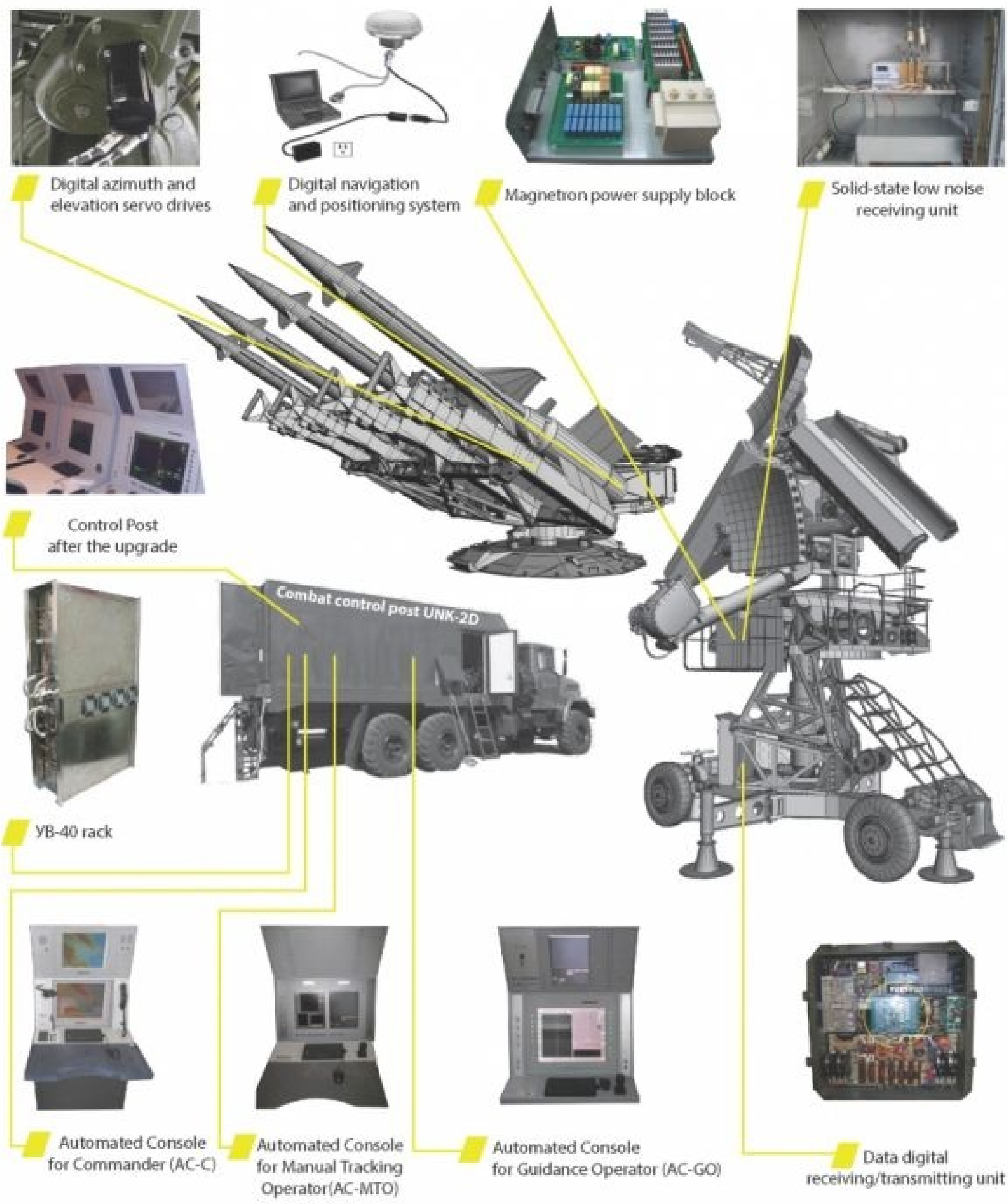


Figure 4-22: Ukrainian AAMC S-125 (SA-3 GOA) Upgrade to S-125-2D Pechora-2D
(Source: UkrOboronEksport)

Chapter Five

Anti – radiation missile (ARM) against radar

Since the middle of the 20th century radars have been destroyed by specialized weapons – anti-radiation missiles (ARM), homing in on the electromagnetic radiation of the radars. Over the decades the radars have been modified and modernized. New ones have been constructed and different exploitation techniques have been developed. The technical progress of these devices is a never-ending competition.

The anti-radiation missiles destroy radars which are elements of the opponent's air defence system, this in turn allows for the free operating of friendly aircraft within the enemy's airspace and then also, during combat within the opponent's territory, their targets are also various objects located there. In the first case, aircrafts carrying these missiles attempt to fulfill the task without entering the striking distance of the ground elements of the enemy's air defence system (rockets and barrel artillery). Such operations demand proper evaluation of the space striking abilities of the system and to ensure the system is equipped with weapons of the proper strike range needed for destroying the defence system elements. In the second case, the air defence system elements are attacked while crossing the border of their strike range. Also, the weapons systems protecting important objects within the opponent's territory are eliminated.

While estimating the influence of the anti-radiation missiles' strike range one cannot neglect the inseparable parameter of the missile flight speed. These two parameters determine the time in which the missile reaches the target after being launched from the plane. Anti-radiation missiles can be divided roughly according to their range into short range missiles (maximum 100 km), mid-range missiles (maximum 200 km) and long-range missiles (over 200 km).

Another important parameter of the anti-radiation missiles is the efficiency of target damage done by the warhead exploding; this is significant for the radar's survival on the battlefield. In the 1950s the low target accuracy of the anti-radiation missiles was compensated by using warheads of high explosive power, large enough for strategic aircrafts to carry them. During the 1960s three

new weight categories of warheads appeared (approximately 150 kg, 86-90 kg and 66 kg); these are still in use with just a few exceptions. In comparison with the former generation of missiles, their higher accuracy and probability of hitting the target allowed for achieving expected striking efficiency in each of these categories. In addition, the distance (altitude) of the fuse from the target was optimized. Such was the situation until the beginning of the 1990s, when the British ALARM missile appeared, whose efficiency is proved by the possibility of attacking a radar with a within 1-meter accuracy (without GPS). For example, the AGM-45 Shrike missile (with approximately a 66 kg warhead) was striking the radars within 15 meters range, and its "A" version was equipped with high explosives containing 20000 cubic piercing fragments (while hitting the target directly or imprecisely with this missile a high striking effect could be achieved), while the Ch-58USzE missile (with an approximate 150 kg warhead) could hit radars within a range of 20 meters. The target accuracy of the Ch-15P and Ch-58USzE missiles is 5-8 meters, of the Ch-31P missile up to 5-7 m, and of the AGM-88 A/B HARM missile the target accuracy is estimated between 7.3-9 m. Also, for the Ch-58USzE missile the target hitting probability within the range of 20 meters is 0.8. The AGM-88C HARM warhead is equipped with 12845 tungsten cubes (5 mm), able to perforate a 12.7 mm thick soft metal sheet or a 6.35 mm thick armoured plate from a distance of 6 meters, maintaining the missile's target accuracy. The German ARMIGER missile has quite a small warhead, only 20 kg, and its target accuracy is less than 1 meter (<1 m). Probably the target accuracy of the American AGM-88E AARGM missile is on a similar level to that of the ARMIGER missile; since both of them are based on the same construction (AGM-88D HARM) and both represent the same technological advancement level.

But in order to deploy the missile within the efficient strike range it must be equipped with a proper guidance system. Missiles produced in the 1950s and 1960s were homed to the electromagnetic radiation of the radars with support of the inertial guidance system only. The whole process was controlled by a technologically simple autopilot. In the 1970s the dynamic development of miniature transistor-circuit systems began, and they were also employed by the constructors of the anti-radiation missiles homing systems. The following two decades were characterised by the improvement of the existing electronics of the missiles, the aim being the possibility of constructing devices equipped with programmable data bases. They allowed for the comparison of the parameters of detected radars and thus the ability to choose those most dangerous or those which have been pre-defined as a specific of a given combat task demanded.

A conventional anti-radiation missile is homed primarily to the radar's mainlobe emission, but also to the emission of its horizontal sidelobes and the backlobes emission – it depends on the distance between the radar and the missile. However, in the case of the older radars the primary target is their horizontal sidelobes and backlobes emission of a very high level, which radiate continually. This allows the missile to have uninterrupted tracking of the radar and the passive antiradiation homing receiver does not become saturated. Modern radars with a very low level of the horizontal sidelobes and backlobes emissions are a "blinking" target for a missile, and the "blinking" is the result of the intervals in receiving the radar mainlobe emission during the turn of its antenna. In such a situation, the on-board systems of missiles without GPS are forced to estimate the radar's position on the basis of an intermittently received emission. When the turn speed of the antenna is low (long intervals in receiving the emission), the guidance system of the missile is supported by its inertial system, especially during the final phase of flight, which often results with a bigger margin of error (a few meters) in detecting the position of the radar than was assumed beforehand. The error is usually increased to such an extent that in the moment of directly hitting the target the warhead is not set off by a contact fuse but by a proximity fuse. In order to maintain the attack efficiency, the warhead must be equipped with a much stronger explosive.

In 1973, during the Israeli-Arabian Yom Kippur War, conventional anti-radiation missiles of the 1950s' generation were used. At that time, Egyptian Tu-16 bombers fired 13 KSR-2 and 12 KSR-11 (KSR-2P) missiles from above the Mediterranean towards the targets located on the coast and inside Israeli territory. Most of the missiles (about 20) were intercepted and destroyed by either the air force or the HAWK surface-to-air missiles. 5 of them penetrated through the Israeli air defence system and reached their designated targets. Three radars and one logistic point on the Sinai Peninsula were eliminated. Missiles of the 1970s' generation were used during the Iraqi-Iranian war (1980–1988) by the Iraqi aircrafts which were targeting Ch-28 missiles towards the radars of the Iranian HAWK systems. Effects of these attacks have not been revealed, unlike the results of the Ch-22MP BURJA missiles which were launched from the Iraqi Tu-22K bombers. Despite numerous launchings towards the HAWK radars, only one missile hit its target. The reason was the poor training of the Iraqi bomber crews, the low efficiency of the guiding system (on the missiles and the deck systems of the bombers), as well as difficulties in efficiently detecting the radars' position from a long distance. Therefore, later the launchings took place at a

distance of 60 km or less and the missiles were carried by the Tu-16 bombers. The targets attacked were mainly located near Teheran: oil refineries and other cities protected by the anti-aircraft system of Iran. The missiles of the 1980s' generation were used for the first time on 15th April 1986 during the US bombing of Libya (Tripoli and Benghazi), code-named "Operation El Dorado Canyon". AGM-88A Harm anti-radiation missiles were homed very efficiently eliminating the radars of Libyan air defence system rocket launchers SA-2 Guideline (S-75), SA-3 Goa (S-125 Pechora) and SA-5 Gammon (S-200 ANGARA) located around the Gulf of Sidra.

Figure 5-1: USN and USMC F/A-18 during the first Gulf War
(Source: ausairpower.com)

In the 1990s the British ALARM missile appeared, introducing some changes in the context of fighting radars. ALARM can be used in the same way as the conventional missiles constructed so far, but in addition it is able to detect and destroy radars independently. It climbs to an altitude of 12000-21000 meters within the task zone. There its engine is turned off, the parachute opens, and the missile starts diving slowly, while its passive anti-radiation homing receiver searches for the target – operating radar. When such is detected, the parachute detaches itself and due to gravity, the missile – directed by the guidance system – moves towards the radar. The ALARM missile was created before GPS started to be used in such constructions and its operating method has its reasons. The so called vertical attack of this missile is a result of an assumption that had been made before even the ALARM project appeared. The passive anti-radiation homing receiver of this missile independently homes itself towards the radar emission radiating vertically up, i.e. towards the vertical sidelobes. Since most of the radars became able to locate the air objects with high accuracy, the emission level of the horizontal sidelobes and backlobes have lowered, in comparison to high emission level of the vertical sidelobes. Regardless of the direction of the mainlobe emission of the radar, the ALARM passive anti-radiation homing receiver is able to track continuously the fluctuating microwave emission leaking upward from the radar's antenna.

Guiding to the vertical sidelobes (vertical attack at an angle of 90^0) has an additional aspect, namely reducing the influence of emission coming from radiation reflected by the ground objects, which in case of attack at an angle of 20^0 – 40^0 normally widens the margin of error. Taking advantage of it, the ALARM missile is able to attack the target with high accuracy. Moreover, the accuracy is 1 meter, i.e. the explosion should be initiated in the distance of 1

meter from the radar antenna, which increases its most explosive power. The programmable warhead of this missile can have a data base containing information on the general construction of every type of radar, which shows, among other details, the place where the antenna is located. This enables the missile to initiate a precise explosion destroying the antenna system or the main electronic systems located in the main blocks of the radar's board (it depends on what task has been programmed before). It is of special importance in case of eliminating radars whose antennas are raised high, designed for detecting also air objects flying at low altitude. It must be emphasized that the warhead of an anti-radiation missile equipped with smaller explosive exploding very close to the antenna will result in the same destruction level as a warhead with bigger explosive exploding at a greater distance.

Such missiles were used for the first time during the First Gulf War (1990–1991). 121 ALARM missiles were launched from British Tornado aircraft, which carried out 24 missions aimed only at destroying the air defence system of Iraq and 52 SEAD missions (Suppression of Enemy Air Defences), operating within the opponent's airspace. In a few cases the launching of the ALARMs of the first experimental series was unsuccessful. In order to eliminate the Iraqi air defence system elements, the coalition forces used also HARM anti-radiation missiles. During the "Desert Storm" operation about 2000 of these were launched at the Iraqi radars. A question might be asked as to whether Iraq really had so many air defence radars. However, one can conclude that these missiles were used on many occasions only preventively. Some sources prove that the initiators of such launchings were mainly the pilots of the US Navy (F/A-18 planes), who were using an imprecise warning system – the first version of ALR-67 RWR, while the crews of aircrafts designed especially for the SEAD missions, carried out well planned selection, had more time for destroying their targets (it is their main task); they were also better trained and equipped, with much better electronics. (**Figure 5-9**)

During the First Gulf War ALARM missiles, climbing vertically, were a novelty for many allied pilots. Quite often the missiles speeding upwards (aiming at reaching maximum speed and starting the parachute dive) were mistaken for Iraqi air defence system rockets, which would alarm the battle group unnecessarily, with accounts of such events becoming transformed into various anecdotes.

The analysis of the conflict of the 1990s and experiences resulting from it led

to the upgrading of some of the missiles by equipping their guidance systems with additional elements.

HARM

One of the most important experiences came from the period of NATO operating over the Balkan Peninsula. During the NATO air operation called “Deliberate Force” of 1995, American AGM-88 HARM missiles of the first versions were used (**Figure 5-1**). In addition, the American F-16 aircraft were already then equipped with the Harm Targeting System (HTS), which was used then for the first time in a combat environment. During the 1999 period of this conflict ALARM, AGM-88B HARM and AGM-88C HARM missiles were launched over Serbia and Kosovo, but they were not able to do serious damage to the extremely mobile Yugoslavian air-defence forces. The damages were symbolic and resulted from the too low accuracy of the inertial guiding systems homing the missiles. This provided a strong impulse for the development and later use of GPS in the guidance systems (**Figure 5-2**).

“NATO planes launched altogether 743 HARM missiles, 6 ALARMs and 8 ARMATs towards the radars of the Yugoslavian air defence forces. However, only about 115-130 of the ground targets emitting electromagnetic radiation were attacked, which proves the high efficiency of the Yugoslavian forces’ operations, i.e. the high discipline level concerning the limited time of radars’ radiation (up to 10 seconds) and the high mobility of the forces (constantly changing the positions of the anti-aircraft weapons). The NATO official reports state that the efficiency of the HARM missiles was 3%-6.6%, depending on the operation’s phase. The high efficiency of the Yugoslavian forces was proved by the fact that during the operations the Americans decided to deploy to Italy their experimental Tiger Team from China Lake Weapons Division (USA), an institution testing new weapons. During just 36 days, its pilots tested over 400 HARM missiles, in order to develop new tactics for launching them, allowing for increased efficiency. The effects of their work were instantly transferred to the US Navy units. As a result, immediately more of the attacked objects were destroyed” (as per US claims, however, this is not confirmed).

This report confirms that NATO used air campaign to test and develop the new systems. It was definitely proving ground for the new products and tactics. Yugoslavia was the laboratory for testing and developing new systems. After the war when one of the authors moved to North America he had a chance to speak with the people from different branches and development centers in USA and

quiet a lot of them confirmed that during the bombing they were stationed in Italy and performed on site evaluation and testing of their equipment.

HARM can be launch from F/A-18, F-16, Tornado, A-6 and attacking aircraft used them on daily basis. Maximum speed of 2200 km/h and range of 150 km gave them long extended hand far in the safety zone out of range of SAM systems. But usually they launch them much closer, to shorten the traveling time to the target. This missile is really fast, flying more than 600 m/s. The crew at the fire control station doesn’t have a lot of time for reaction before they are hit. Calculation shows that if the airplane is 30 km away, just out of SAM missile effective engagement zone, and launch the missile, the crew in the fire control station has about 49 seconds before the impact but if the airplane is flying supersonic speed and flying toward the target and within the range of the missile, than the crew will have maximum 25 seconds to turn on target guidance radar, acquire the target, lock onto the target, and launch the missile. The few seconds is just the safe margin to turn off the radar before HARM hit it (**Figure 5-3**).

HARM poses around 60 kilograms warhead that is WDU-21/B blast-fragmentation in a WAU-7/B warhead section, and later WDU-37/B blast-fragmentation warhead. A blast fragmentation type warhead in HARM is designed to destroy enemy radars and vehicles such as command modules. When the missile carrying the warhead reaches a position close to an enemy missile control radar or other target, a pre-scored or pre-made band of metal on the warhead is detonated and pieces of metal are accelerated with high velocity and strike the target. Approximately 30% of the energy released by the explosive detonation is used to fragment the case and impart kinetic energy to the fragments. The balance of available energy is used to create a shock front and blast effects. The fragments are propelled at high velocity, and after a short distance they overtake and pass through the shock wave. The rate at which the velocity of the shock front accompanying the blast decreases is generally much greater than the decrease in velocity of fragments, which occurs due to air friction. Therefore, the advance of the shock front lags behind that of the fragments. The radius of effective fragment damage, although target dependent, thus exceeds considerably the radius of effective blast damage in an air burst. Radar, guidance station and everything on the path is covered with fragments. The missile consists of four sections; guidance section, warhead, control section and rocket motor. The AGM-88A missile is powered by a Thikol SR113-TC-1 dual-thrust (boost/sustain) low-smoke solid-fueled rocket motor and has a 66 kg

(146 lb) WDU-21/B blast-fragmentation warhead (25000 steel fragments) in a WAU-7/B warhead section. The warhead is triggered by an FMU-111/B laser proximity fuse. The seeker of the WGU-2/B guidance section has to be pre-tuned to likely threats at depot-level maintenance, so every base or ship has to store a selection of differently tuned HARM seeker heads. In flight, the AGM-88 is controlled by the WCU-2/B control section using four movable BSU-59/B mid-body fins and stabilized by the fixed BSU-60/B tailfins.

The HARM can be used in three different operational modes, known as Pre-Briefed (PB), Target-of-Opportunity (TOO), and Self-Protect (SP). In PB mode, the long range (up to 150 km (80 nm)) of the AGM-88 is used to launch the missile on a lofted trajectory toward a known threat. When the HARM reaches lock-on range, and detects the radar emission, it can home on the target. If the target radar has been switched off before any lock could be acquired, the missile destroys itself to avoid possible friendly casualties by the impact of the now unguided missile. In SP mode, the aircraft's radar warning receiver is used to detect enemy emissions. The CP-1001B/AWG HARM Command Launch Computer (CLC) then decides which target to attack, transmits the data to the missile, and launches the AGM-88. TOO mode means that the seeker of the AGM-88 itself has detected a target, and the missile can be fired manually if the radar emission is identified as a threat. In SP and TOO modes, the AGM-88 can even be fired at targets behind the launching aircraft, although this of course significantly reduces the missile's range. The AGM-88 missile has an inbuilt inertial system, so that whenever it has acquired a lock once, it will continue towards the target even if the emitter is shut down (although the CEP is larger in this case) (**Figure 5-4**).

The basic protection from HARM attacks is relatively simple. Majority of missile units applied tactics of short radar emissions which worked very well. One of the very useful field measures was to use wooden logs to protect the crews in the fire control center (UNK) and power generation van. Lt Col (**Figure 5-5**, **Figure 5-5**). Djordje Anicic applied that for the first time at the 3rd missile battalion. This high velocity fragments after warhead explosion may cause damage to radar antennas, fire control station and may cause the crew casualties. As an extra layer of protection, the combat crews started to use helmets and ballistic vests. Military developed radar emissions imitators greatly contribute to the protection form HARM’s attacks but they were never available in large numbers for all air defence units (**Figure 5-7**).

HARM has a proportional guidance system that homes in on enemy radar emissions through a fixed antenna and seeker head in the missile nose. To confuse the HARMs guidance system, reflectors were raised 5-6 m above the ground (as high as possible) to try to activate the proximity fuses in the warhead before the impact on the real object. Signal when emitted from the missile hit reflector and because the reflection is large hopefully will initiate the explosion.

There were some articles in the press and internet mentioning use of ordinary kitchen microwaves to confuse the HARM's sensors and that Yugoslavs used them extensively. That was never applied in practice. Theoretically it is possible, but those microwaves need a power supply. Hundreds of meters of power cables are needed. Air defence units struggled with their own cables to power the equipment and they didn't have them in enough number.

Large number of radar reflectors, log protection and camouflage and false firing control radar emitters were the optimal solution against HARM. And of course, short cycle radar emissions.

The other solution is use of specially built decoys. The aim of using decoys is to lure an HARM to detonate in an area where it does not cause harm to the radar, and if possible, to the decoys either. The warhead of the missile is assumed to be small enough that the usage of decoys is practical, i.e., the missile is not able to destroy all the transmitters if they are not placed right next to each other. The effect of the fragments is omitted. The decoy itself is a transmitter that repeats the same waveform as the protected radar. The passive seeker of the HARM cannot separate the transmissions of the decoys from those of the radar based on, e.g., modulation, pulse width or carrier frequency. Therefore, the decoys can offer great protection against the threat posed by the HARM. A desirable feature of the decoys is that the radar can continue transmitting in order to provide surveillance information. Another feature is that in the case of successful deceiving, the same decoys can be reused against a new HARM.

The effectiveness of decoys depends on their transmission power and location. If the transmission power is set too low compared to the side lobe level of the antenna of the radar, the decoys fail to lure the HARM. Setting the power too high makes the decoys vulnerable to the HARM. Similarly, regarding the locations, the decoys that are too far from the flight path of the HARM may not lure it whereas being too close makes the decoys vulnerable. Although it is better to sacrifice a single decoy instead of the radar, the best outcome is the one where

both survive. In studies related to the usage of decoys, the locations of the decoys are usually assumed to be known or there are few possible locations, but the decoys are not assigned to the locations in an optimal way. As the locations may considerably affect the outcome of survival, there is a need for an approach for determining the best possible locations. In reality, such planning is also affected by the geographical area which limits where the decoys can be placed.

What was more dangerous than HARM missile is that if the surveillance airplane pinpoint location of the missile battery, the attack of the bombers was imminent, and NATO used laser guided bombs or even ordinary gravity bombs to destroy the targets.

How this works: a laser is kept pointed at the target and the laser radiation bounces off the target and is scattered in all directions. The missile, bomb, etc. is launched or dropped somewhere near the target. When it is close enough for some of the reflected laser energy from the target to reach it, a laser seeker detects which direction this energy is coming from and adjusts the projectile trajectory towards the source. While the projectile is in the general area and the laser is kept aimed at the target, the projectile should be guided accurately to the target. However, this is not useful against targets that do not reflect much laser energy, including those coated in special paint which absorbs laser energy. Countermeasures to laser guidance are Laser detection systems, smoke screen, anti-laser active protection systems. Unfortunately, some of the missile battalions were hit on this way and the equipment obliterated. The worst were when the people got killed. The chance to avoid and survive the attack was that the laser locks the weapon onto the decoy. That is where camouflage plays the crucial role (**Figure 5-8**).

New Century

The best-known military conflict of the first decade of the 21st century, during which anti-radiation missiles were used, was the Second Gulf War of 2003. The elements of the Iraqi air defence system were being then destroyed by, among others, the HARM missiles – over 400 of them were launched towards all kinds of Iraqi radars. Taking into account the economic situation of Iraq and its low possibilities of recreating its air defence system after the war of 1990-91 and various subsequent air operations (e.g. “Desert Fox”), the number of launched anti-radiation missiles might seem too large, especially that they were better developed technologically and also the AGM-88C HARM missiles were already accessible. At that time, the American planes were already equipped with an

instrument for launching the anti-radiation missiles for self-protection, and probably this function was used excessively by the crews of the combat planes carrying such missiles.

The most recent military conflict, during which the anti-radiation missiles were used, was the war in the Southern Ossetia of 2008 (Georgia's forces vs. combined forces of Southern Ossetia, Abkhazia and Russia). At that time, the basic equipment of the Georgian radar forces was a few ST-68U (36D6-M) radars of Soviet production; they were quite difficult to be manoeuvred. In a relatively short time, the Russian air forces managed to eliminate all Georgian radars.

All the above-mentioned experiences triggered further development. The first decade of the 21st century was a period of intensified development of the guidance systems homing the anti-radiation missiles towards the radars. These systems became equipped with GPS: American AGM-88D HARM and AGM-88E AARGM missiles, German ARMIGER missiles and Israeli STAR-1 missile. In addition, ARMIGER was also equipped with an Infrared sensor, providing a picture processed by a special system. Probably, this was caused by the fact that earlier the German TORNADO.ECR, specialized aircraft equipped with such sensors, was able to lower the electromagnetic emission of the plain's board. But it was the configuration of the AGM-88E AARGM missile that was subject to greatest modification. This missile does not have an Infrared sensor, but it is equipped with active millimetre wave radar with an extremely precise Doppler modulator (active radar seeker), which increased the possibilities of fighting both stationary and mobile targets (e.g. a radar changing position after being turned off). Also, this missile contains a system for information exchange via radio (used for updating the data on the radar for the missile – as a part of targeting – and in order to transfer information about the radar being fought, recorded just before the moment of explosion of the missile hitting the target). The systems built in the AGM-88E AARGM missile allow its own millimetre wave radar to fully cooperating with the digital passive receiver of electromagnetic waves. This makes the radar operator unable to stop the missile's attack on the radar by turning it off, changing its combat position or turning on a decoy – a radar electromagnetic trap imitating the radar's signal meant to attract the missile away from the real radar, i.e. creating a false location of the attacked radar. The head of the millimetre wave radar is meant to track the location of the attacked radar in a way which allows the missile to hit the real radar and not the false source of emission (decoy), even if the radar would start to move. Also, it is worth mentioning a slightly different type of anti-radiation missile, namely the American AGM-136 TACIT RAINBOW and Israeli STAR-1

missiles. They are in fact cruise missiles, in which the warhead is built into the vehicle and which after being launched travel in front of the air strike force following a pre-programmed flight path. Their task is to destroy the anti-aircraft radars located in the plane's flight path (**Figure 5-10**).

The second decade of the 21st century brought only scant promises for the construction of new missiles, regardless of the fact that the scientists of many states must be working on new technical solutions. In 2012 it was announced that new Russian anti-radiation missiles shall have the same possibilities which already characterize their existing Western counterparts. The code of the Ch-31PD missiles (probably produced in 2003) reveals only their serious modernization (mainly of the warhead), which shall be surely based on the exploitation of the satellite guiding homing systems. Obviously, it may be expected that because of the expected export, the Russians will not use the Russian Glonass satellite system exclusively and they also will produce a missile version using the Western GPS system. Of course, applying a completely new technical guiding solution cannot be excluded (e.g. the German ARMIGER – additional use of Infrared sensor). In the case of a solution similar to the AGM-88E AARGM (additional active millimeter wave radar), the basis of such a construction can be a warhead of an already existing missile (e.g. Ch-15S, Ch-25MAE or Ch-58A). Time shall show the direction of Russian military technological development.

Evaluating the development of the existing anti-radiation missiles, one could single out a few main ways of fighting radars:

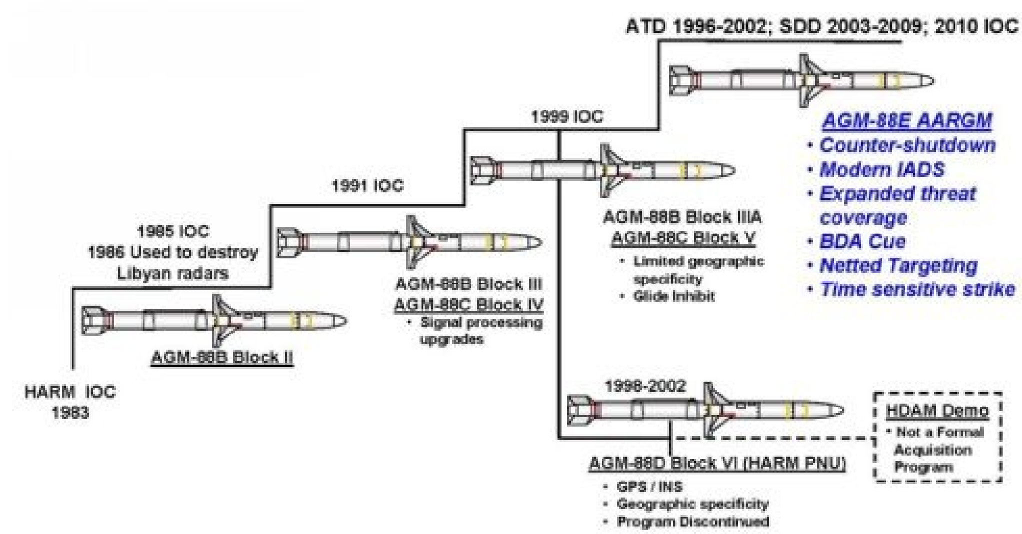
- direct attack – a missile launched usually at a middle- or long-distance climbs to a great altitude (e.g. for Ch-32P it is 22000 meters), then accelerates, achieving its maximum speed in the final phase of the flight, denying thus the radar crew the ability to react to the attack. The target may be hit at a classical angle (like most missiles, between 20^0 and 40^0) or vertically (90^0 – ALARM missile);
- shallow dive trajectory attack – the missile is usually launched from a short distance, it attacks the radar in a shallow dive trajectory, and it does not achieve maximum height, moving with optimal cruise speed;
- delayed attack – the missile may be launched at any height, it reaches its maximum height, then turns off the engine and starts diving with a parachute, which detaches after detecting the radar; then the

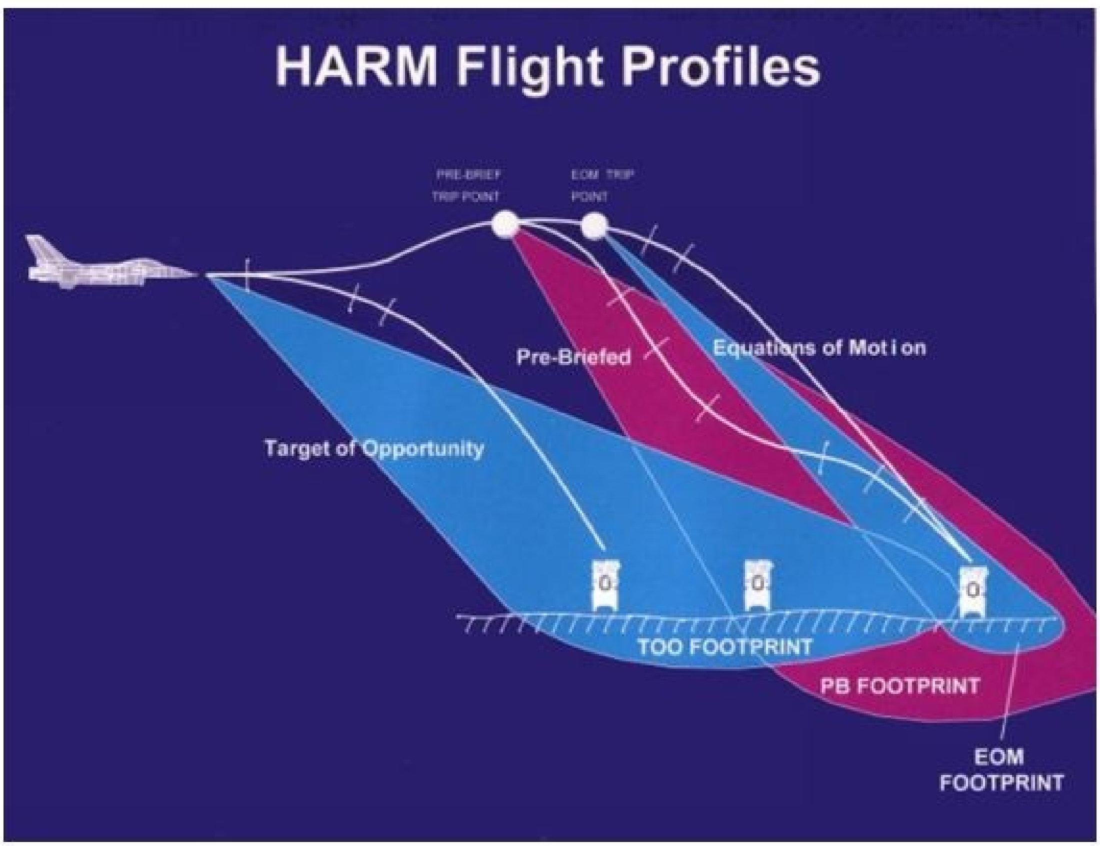
missile due to gravity falls down, homing towards the target (vertical attack at an angle of 90^0, performed nowadays only by the British ALARM missile – so called “loiter mode”);

- manoeuvring attack – a cruise anti-radiation missile built as a plane (it can be manoeuvring in a defined area and waiting for a radar to be turned on), and its main task is destroying the anti-aircraft radars located in the planes flight path (e.g. American AGM-136 TACIT RAINBOW or Israeli STAR-1 missiles).

The construction of modern planes and the modernizing of them is nowadays aimed at adjusting them to simultaneous ability to carry arms from the weapons factories of the West and the East. The last operations are also forced by the companies fighting for the right to sell weapons abroad. Also, many countries have in their arsenals anti-radiation missiles from different technological eras, which results in the fact that in the field of combat any type of missile may appear.

Figure 5-1: USN and USMC F/A-18 during the first Gulf War
(Source: ausairpower.com)


ATD 1996-2002; SDD 2003-2009; 2010 IOC
1999 IOC
AGM-88E AARGM
• Counter-shutdown
• Modern IADS
• Expanded threat coverage
• BDA Cue
• Netted Targeting
• Time sensitive strike
1991 IOC
AGM-88B Block IIIA
AGM-88C Block V
• Limited geographic specificity
• Glide Inhibit
1985 IOC
1986 Used to destroy Libyan radars
AGM-88B Block III
AGM-88C Block IV
• Signal processing upgrades
AGM-88B Block II
HARM IOC 1983
1998-2002
HDAM Demo
• Not a Formal Acquisition Program
AGM-88D Block VI (HARM PNU)
• GPS / INS
• Geographic specificity
• Program Discontinued


HARM Flight Profiles
PRE-BRIEF TRIP POINT
EOM TRIP POINT
Pre-Briefed
Equations of Motion
Target of Opportunity
TOO FOOTPRINT
PB FOOTPRINT
EOM FOOTPRINT

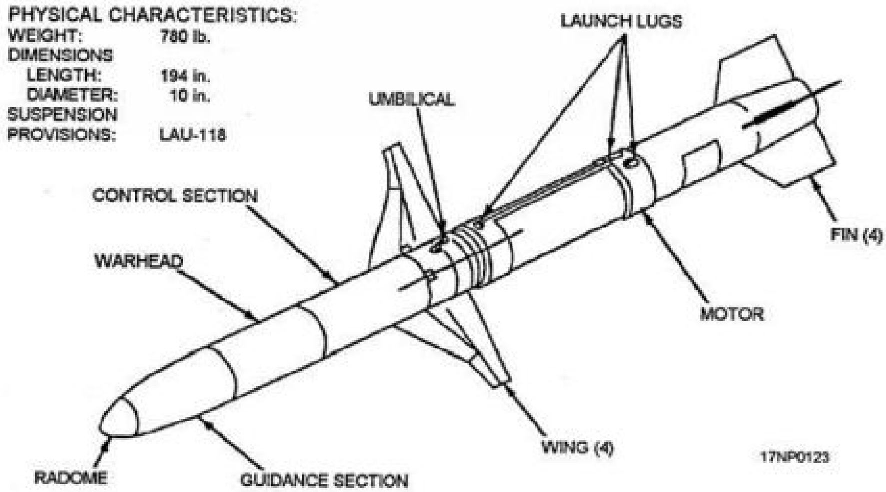


Figure 5-3: AGM-88 HARM
(Source: T.O.GR1F-16CJ-34-1-1)

Figure 5-6: Fire control and command van field log protection - extensively used against HARM during 1999 (Source: authors)

Figure 5-5: Field log protection against HARM (Source: authors)

Figure 5-7: Fire control radar imitator. Very effective way to "confuse" the anti-radiation missile guidance system (Source:mycitymilitary.com)

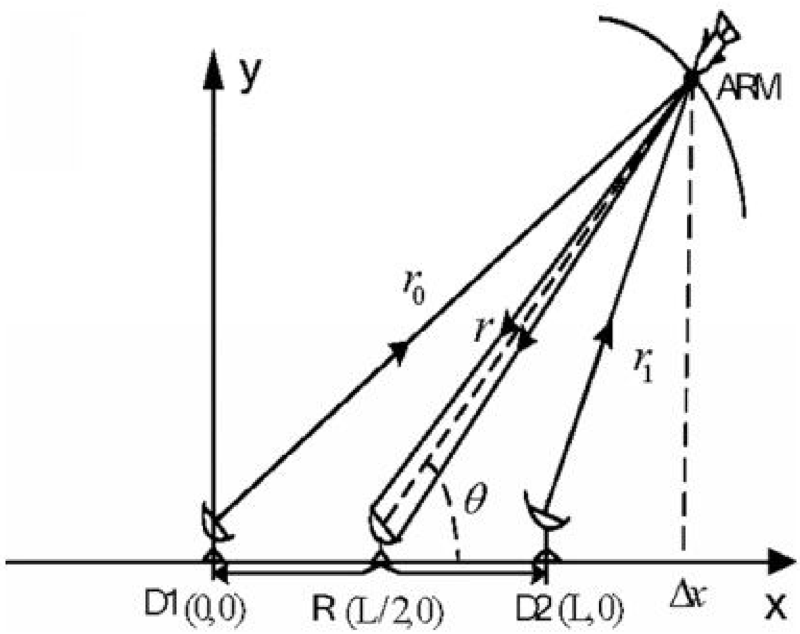


Figure 5-8: Dual frequencies coherent decoys (D1 and D2) jamming ARM (Source: IEEE 2013)

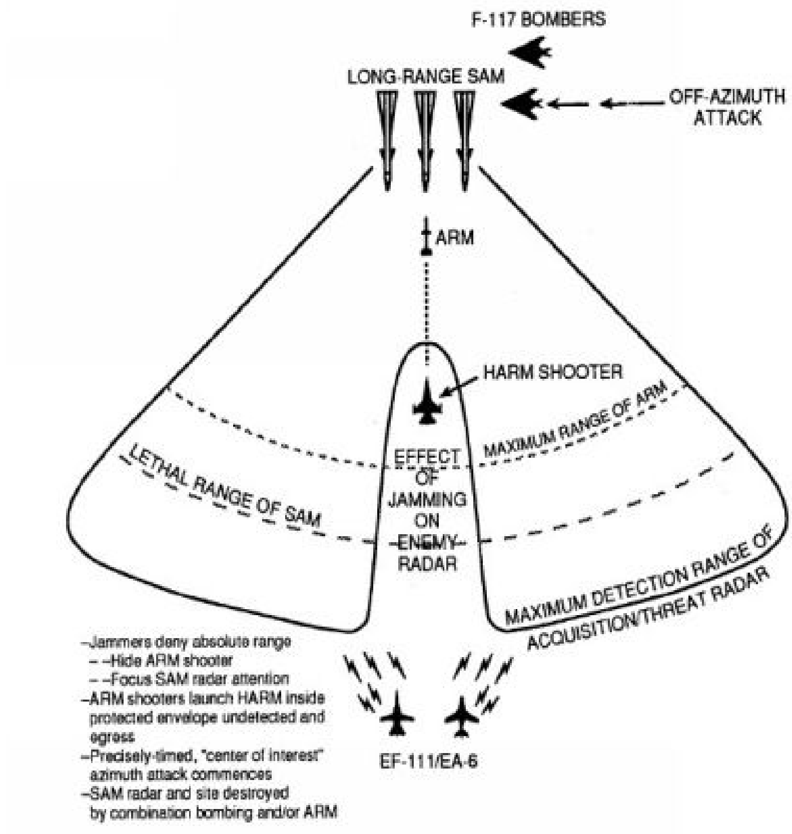


Figure 5-09: Attacking the SAM site (Source: Setting the contest: SEAD and joint war fighting)

Figure 5-10: AARGM (Source: ATK)

Chapter Six

SA-3/S-125 Combat Engagements

As is known, the most vivid period in the history of the anti-aircraft missile systems, such as SA-2/S-75 was during the Vietnam War during which these weapons were used quite intensively, which to a large extent determined the nature and outcome of the fighting. In the mid-1960's the S-125 complexes were still considered extremely secret technology, so the Soviet leadership didn’t want to use it or deliver to the North Vietnamese because in the time of the stretched relations with China and the conflicts on the border there were possibility that the Chinese experts may be allowed to “lay there hands” on the most modern Soviet missile system.

The S-125 golden hour came in the spring of 1970, when a large group of missile men and pilots were sent to Egypt under the decision of the Soviet leadership in the process of conducting the operation "Caucasus". They were called upon to provide air defence of this country in the conditions of the increased raids of Israeli aviation, carried out during the so-called "War of Attrition" of 1968-1970. The fighting was conducted mainly in the zone of the Suez Canal, to the east bank of which the Israelis fortified after the victorious for them Six-Day war of 1967.

Early in February 1970, American and Israeli intelligence did detect large new Soviet air and sea shipments of equipment to Egypt, but the first really disquieting news was not received until 25 February, when on a secret briefing in the White House it was told that a large number of Soviet aircrafts and cargo ships carrying SAM-3s batteries and radar and Soviet military crews had begun to arrive in Egypt. A complete air defence system, including SAM-3s missiles and some eighty fighters (MiG-21 and MiG-23), had to be installed

The whole operation of the delivering the missile system to Egypt was carried out in secrecy and dozen cargo ships were engaged transporting the equipment under the cover of transporting the agricultural equipment.

The SA-2/S-125 air defence missile battalions with Soviet personnel were called upon to strengthen the Egyptian air defence forces equipped with the older S-75 air defence system. The main advantage of the Soviet missile system, along with a higher level of training and proficiency, was the novelty for the Israelis, as well as for the Americans supporting them, the features of the S-125 complex operating in a slightly different frequency range than the already very well-known S-75. Therefore, at first, Israeli aircraft were not equipped with effective means of electronic countermeasure to counter S-125. In addition, using the flat

nature of the terrain, Israeli pilots, as a rule, operated at extremely low altitudes inaccessible to the effective use of the S-75. Attacking these complexes, they performed a slide run and dived into the "funnel" of the non-shooting zone above the position of the SAM.

War of Attrition and Yom Kippur War

Sending to Egypt of Soviet short-range anti-aircraft systems provided more protection to the SAMs. In particular, for self-defence of the SAM positions, each battalion was assigned three to four anti-aircraft self-propelled ZSU-23-4 Shilka vehicles and a Strela-2 portable should launched anti-aircraft missile systems. Later in Egypt, "Shilka" was located 200-300 meters from the position of the SAM, and the positions of "Strela-2" operators were put forward about 5-7 km in the direction of the probable directions of enemy aircraft. Strela 2, early versions, could engage the enemy aircraft only from the back, thus meaning that the aircraft fly over the position of the shoulder launched system, and approaching to the SAM positions. Visual observers were also put on the perimeters. The connection between all the posts and the battalion command post was carried out by wired phone lines. During the combat use of the S-125 complex in Egypt, DShK machine guns were also used for site defence.

The new air defence from the Soviet Union needed special installations which had to be constructed under continuous pressure from enemy air raids, day and night. The Egyptians were beginning large-scale construction works along their second defence line, some 15 to 30 kilometres west of the Canal. From the beginning of March Israeli planes were sent to attack the works. The Israelis concentrated all the power of its air force on preventing the Egyptians from preparing the reinforcements and positions for the new missiles in the Canal area. Egyptian engineers prepared the combat positions building the protective structures for placing the cabins and units of the complex. Reinforced concrete structures, covered with a layer of sand 4-5 m thick, provided reliable protection against bombs up to 500 kg. The missile launchers were protected with embankments. The tactic was to create the primary position and few reserve positions as well as the decoy positions.

The operation exacted tremendous cost in lives, both military and civilian, and was accomplished under the worst imaginable conditions. Setting up the installations for the air defence became a national symbol, a test of will and self-sacrifice. The volume of the necessary engineering works was enormous and was completed in forty days.

The first S-125 engagement was bloody. On the night of March 14-15, 1970,

Soviet missile combat crew made a debut by shooting down an Egyptian Il-28, which entered the zone of destruction of the S-125 air defence system at an altitude of 200 m. “Friend-or-Foe” transmitter on the Il-38 was out so the missile crew had no chance to check the origins of the airplane. Alongside with the Soviet officers, there were also Egyptian officers who were there as a liaison and they assured soviet missile crew that there is no friendly aircraft in the zone of fire. The combat crew engaged the target and launched the two missiles that struck the plane.

Three days later the second incident happened when one of the shoulders launched operators on Strela-2 missile, which covered the position of the Soviet S-125 battalion, also fired upon the Egyptian airplane, this time An-24. Fortunately, a passenger plane with one idle engine held out to the airfield and landed safely. The incident was firstly reported as an "inglorious end of the Israeli aggressor". It was obvious that the coordination between the soviet crews and Egyptian liaison didn’t work properly. The Egyptian did not provide the safe routes to their airplanes and didn’t have timely mannered connections with the airplanes in the air. Missile crews acted as per regulations and procedures. By all means, it was the time where Israelis also performed combat sorties over the Egyptian territory.

Nevertheless, in a few weeks it came the engagement of the real enemy. In the beginning they were unsuccessful. Israeli pilots in their pre-flight briefings were briefed of the main location of the missile batteries and they tried to bypass the zones of destruction of the SAM, deployed in positions with defensive structures. Shooting on enemy aircraft, located on the far edge of the launch zone, resulted in the fact that the Israeli pilots managed to turn around and escape.

What was necessary is that the SAM tactics needed to be corrected and adjusted. The missile systems complexes were withdrawn from the permanent areas very well known to the Israeli pilots, to the "ambush" position on unprepared locations which were hard to detect. To mention, because of the desert terrain, it was just a matter of time for Israeli reconnaissance airplanes to pinpoint the new locations thus including the often relocations. Missile launches were carried out at targets ranges up to 12-15 km, not on the farthest range so that the target does not have time to counter missile maneuvers. Combat engagement is far different from the peace time shifts and crews constantly needed to improve their combat skills in the real conditions. Soviet missile crews

also improve the mobility of the system cutting the time to relocate from one position to another.

As a result, on June 30, 1970, Captain V.P. Malauki battalion managed to bring down the first "Phantom", and five days later the battalion of S.K. Zaversnitsky "piled up" the second F-4E. It was followed by the retaliatory attacks by the Israelis and in the course of a fierce battle on July 18 in the battalion of V.M. Tolokonnikov eight Soviet servicemen were killed. Israelis lost four "Phantoms". Three more Israeli planes were shot down by the battalion of N.M. Kutyntsev on August 3, and a few days later, with the mediation of third countries, an agreement was reached to cease of hostilities in the Suez Canal zone.

The information given above on the combat operations of the Soviet missile system is based on the memories of the participants in the events published in the 2001 collections "Then in Egypt" and "Internationalists". According to the commander of the deployed in Egypt Soviet Air Defence battalion, Lieutenant - General A.G. Smirnov, the effectiveness of the combat use of the S-125 air defence system from June to August 1970 is characterized by nine shot down and three damaged enemy aircraft, and according to several estimates of other veterans the SAM's achieved 21 victories. The Israelis themselves confirmed the loss of only five of their F-4E aircraft shot down by the S-125 systems. Casualties on the Soviet side were never published, but the western estimates are that several battalions were hit with the equipment and material losses. S-125 were instrumental in forcing Israel to accept UN ceasefire.

The Yom Kippur War was the fourth in a sequence of major Arab - Israeli conflicts that followed the formation of the state of Israel. Two of the three preceding conflicts - the War of Independence in 1948 and the Six-Day War of 1967 - had resulted in clear Israeli victories. The Six-Day War in particular had been a remarkably one-sided contest. The Israeli Air Force had launched a pre-emptive attack that destroyed its Egyptian counterpart in a single morning. Israeli combined arms force subsequently raced to victory on multiple fronts, taking possession of significant areas of Egyptian and Syrian territory - the Sinai Desert to Israel's south and west and the Golan Heights in the northeast. Israeli forces also seized the Jordanian West Bank and - most symbolically for the Jewish state - took sole possession of the city of Jerusalem. In that war, Israel established territorial defence in depth and won an astonishing military success (**Figure 6-1**).

Prior to the beginning of the Yom Kippur War in October of 1973, the Egyptian commander, Field Marshal Ismail Ali ordered his commanders and staff to study the lessons of the past combat experiences especially in the area of the use of air defence against the powerful Israeli Air Force. Ismail Ali recognized that the Israeli Air Force had achieved air superiority. The Israelis were using the F-4 Phantom and the A-6 Skyhawk, provided by the US. These aircraft were equipped with a dazzling array of sophisticated weaponry and electronics which defended them against Surface to Air Missiles. The aircraft carried television guided bombs and thermal rockets. They also had state of the art radar jamming equipment, SAM evasion electronics and Electronic Counter Measures (ECM) with which to defeat SAMs.

Ismail Ali determined that Egypt would have to establish a sophisticated, modernized air defence umbrella utilizing SAMs and anti-aircraft guns. The Egyptians installed an interlocking SAM system over the Suez Canal in order to protect their rear areas and airfields. The Egyptians learned their lessons well from the 1967 War. They updated their system from the SA-2 to the SA-3, SA-6 and the SA-7, all supplied by the Soviet Union. These were state of the art SAM systems in use by the Soviets. Additionally, SAM batteries were moved in echelon from Cairo to the Suez Canal, which would be the Line of Departure for the Arab assault forces. Moving the batteries forward progressively and slowly, enabled the Egyptians to build up their umbrella without the Israelis realizing it. By June 1970, there were four echelons of SAM batteries between the Egyptian capitol and the Suez.

The Egyptians planned to launch their offensive on a very broad front across the Suez, attempting to deny the Israelis the opportunity of using interior lines and preventing them from concentrating their firepower against a flank. The Egyptian high command ordered their troops to attack on a 170-kilometer front across the Suez. They planned to send unsupported infantry across the Canal and have them establish a bridgehead with a depth of ten to fifteen kilometers. Once bridges were built across the Suez, armor support would come across, reinforce the infantry, and allow the drive to continue into the Sinai. The Egyptians planned on using forward deployed Air Defence assets to protect exposed infantry from Israeli air attacks.

Massed formations of Egyptian armor and infantry, backed by artillery and air strikes, assaulted across the Suez Canal in the afternoon of October 6. Simultaneously, Syrian forces - later supported by Iraqi and limited Jordanian

detachments - attacked Israeli positions on the Golan Heights. The Israeli Air Force scrambled aircraft to support embattled ground forces; however, Egypt and Syria had received huge shipments of Soviet air defence equipment since the end of the War of Attrition and dense SAM ‘umbrellas’ shielded Arab forces from Israeli Air Force attacks on both fronts. Desperate mobilization during the first few days barely prevented an Israeli collapse, and, by 8 October, Arab forces had made consolidated gains in both the Golan and the Sinai.

The Israelis greatest mistake prior to the 1973 War was that they underestimated the Egyptians. The Israelis had been proclaiming to the world for years that the Egyptian army was inefficient, unimaginative, and lacking in will to fight. The problem began when the Israelis believed their own propaganda. The Israelis relied on the Suez Canal to protect them from invasion, as well as a series of fortresses on the Sinai Peninsula, thought to be invulnerable. On October 6, 1973, the myth of Israeli invincibility was shattered. The Israeli Air Force flew 446 daytime sorties and 262 night missions. Because of the efficiency of the Egyptian air defence umbrella, all missions failed to reach their targets. The accuracy and deadly effect of the air defence system devastated the Israeli Air Force.

The Israeli Air Force found itself trapped by operational circumstances in October 1973 and unable to prosecute the type of campaign that it had prepared for. Extant Israeli doctrine prioritized air power missions. The primary role was defence of Israeli territory. The destruction of an enemy’s air force was then the dominant offensive mission. Experience of Soviet-supplied air defences during the War of Attrition meant that a third priority, the destruction of the enemy’s ‘anti - aircraft system’, had become a prerequisite for the final role, the provision of “flying artillery” in interdiction strikes and close support of ground forces. However, the surprise Egyptian and Syrian attacks forced the Israeli Air Force straight into this interdiction role before enemy defences could be targeted. This exposed Israeli aircrews to the full capabilities of Soviet SAM and gun systems possessed by the Arab nations.

The first days of the air campaign were therefore traumatic for the Israeli Air Force. In the southern sector, the Israelis lost as many as 14 strike aircraft in the first three hours of the war alone. The Israelis launched a preplanned operation against Egyptian air defences on 7 October, “Operation Tagar”, but this was compromised by the coincident need to attack Egyptian ground formations. Moreover, only the first phase of Tagar, focused on the suppression of Egyptian

airfields and some AAA sites, could be completed before the air force was diverted to support operations in the north. Egyptian SAM sites were therefore left untouched. The operation was viewed as a failure. In fact, for many senior Israeli Air Force officers, the incomplete execution of Tagar was the most critical mistake of the war, denying Israel an early victory in the Sinai.

Early failure was equally stark in the northern sector. One hundred and twenty-nine sorties were flown against ground targets in the first 30 hours of fighting but Israeli ground forces were pushed back, and Israeli aircraft losses were high. The potency of Syrian SAM defences in these early hours of the war was evident in the fate of a close air support mission attempted at dawn on October 7. An entire four-ship of A-4 Skyhawks, called in by infantry commander Lieutenant Colonel Oded Erez, was shot down by Syrian missiles. A second flight of Skyhawks lost two of its number to further missiles as appalled Israeli ground troops watched. Given such losses, Erez quietly “declined to call for any more air support.” The Israeli Air Force attempted to prosecute a preplanned operation against the northern Syrian defences later on October 7, "Operation Dugman". As in the south, however, the operation was a failure. The Israelis lacked updated positions for mobile SA-6 systems, and electronic warfare helicopters had been transferred to the Egyptian sector and could not be repositioned in time. Desperate calls for close air support by ground forces engaged on the Golan Heights further compromised Israeli Air Force efforts to focus on the counter-SAM mission. As a result, the Dugman attacks against Syrian missile sites resulted in the destruction of only a single SAM battery - and the loss of six F-4 Phantoms, with another ten heavily damaged. The failure of Operation Dugman has been called the “most important defeat in the history of the IAF.” Israeli Air Force confidence was shaken, and the air force remained committed to close air support missions without having achieved control of the air. By the end of October 7, the Israeli Air Force had lost 14 aircraft during 272 strike sorties in the Golan, a localized attrition rate of over five percent.

In the south, the Israeli Air Force achieved freedom from ground threats only when Egyptian forces attacked beyond the coverage of their SAM ‘umbrella’ on October 14. The results were decisive - the Egyptians lost 260 tanks to Israeli ground and air attack in the largest tank battle since the Battle of Kursk in 1943. This Egyptian reverse was followed by an Israeli armored raid across the Suez Canal on October 16 during which Israeli forces destroyed a number of SAM positions.

The Israeli tankers' actions in support of the air force derived mutual benefit. The partial collapse of the Egyptian SAM 'umbrella' allowed the Israeli Air Force to provide effective close air support to Israeli troops in the canal zone. Attrition rates fell. The Air Force lost only four aircraft during 2,261 strike sorties in the Sinai zone between the canal crossing on October 16 and the end of the war on October 24.

Syrian air defence were never truly degraded in the northern zone. Echoing the experience in the south, the Israeli Air Force enjoyed freedom of action only when the ground battle moved beyond the range of Syrian SAMs. The Israelis were here assisted by the deployment of the Syrian air defence well to the east, and the reluctance of Syrian commanders to redeploy SA-6 systems to support early gains. Arab formations that maneuvered beyond the extent of their air defence coverage were decimated by Israeli ground and air forces, just as in the south. However, a combination of the persistent air defence 'shield' and heavily fortified rear positions ultimately created a stalemate in the Golan. Although Israeli counterattacks pushed Syrian and allied Arab forces back from their start positions to within 40 km (24 miles) of Damascus, the front stabilized by the middle of the second week of the war and Israeli efforts were increasingly transferred to the Sinai.

Overall, Israeli Air Force support to ground forces had been compromised by dense Arab air defences, especially in the early part of the war. However, the Israeli Air Force was not totally ineffective, and it achieved significant successes in other roles. The Israelis maintained clear dominance in air-to-air combat. Despite these successes, however, it was the difficulties experienced by the Israeli Air Force, and especially their struggles against Soviet-supplied Arab air defences, that attracted most analysis in the war's aftermath. The Israeli Air Force lost approximately 100 aircraft in less than three weeks of fighting and struggled to impose itself on the ground battle. As the war ended, it appeared that the future of tactical air power was in doubt. It seemed that the "missile [had] bent the aircraft's wing." Israeli and international observers set to understanding what this meant for the future of air power. For a watching US Air Force, the uncomfortable view was of Soviet missiles bending American-supplied wings (**Figure 6-2**).

When the Israelis recognized the effect that the Egyptian AD was having they changed the prioritization of targetry to hitting enemy AD sites first before engaging other targets. Such operations are known as Suppression of Enemy Air

Defence (SEAD). The Israelis put the lessons learned from the American air experience in Vietnam into place with respect to engaging targets and attempted to attack enemy SAM sites first. However, the Egyptians had anticipated this and deployed anti-aircraft guns around their SAM sites in order to protect them against low flying aircraft. These smaller weapons forced the Israelis to abandon their low altitude approaches and attack the SAM batteries from a higher altitude, exposing them to SAM fire. The Egyptians also showed a high degree of field expediency in protecting their SAM sites. They used fire barrels to attract thermal rockets and smoke screens to throw off the television guided rockets. In the face of primitive Arab methods, Western technology was sometimes rendered obsolete.

The Israelis also learned a hard lesson in radio security. During the opening phase of the war, the Israeli air commander broadcast an attack order to his pilots over a radio channel in the clear that was monitored by the Egyptians. As a result, the SAM batteries were waiting for the Israelis.

According to the Soviet analyses, Syrian defence shot down 43 Israeli airplanes using S-125 and losing 5 of its own battalions. According to the same Israeli estimates, six of their planes were shot down by the Arab S-125 air defence system during the October 1973 war. Somewhat earlier, Americans recorded one S-125 from their "Phantoms" shot down over Vietnam in 1972 but this is questionable because S-125 was not in use in Vietnam at that time (**Figure 6-3**).

For intelligence officers, the lesson learned is that when analyzing an opposing force, analyst must be cognizant that opponent will learn from their own mistakes and will change their methods as needed to compensate for own strengths. An opponent's capabilities are not static, they will attempt to overcome their own friction and mitigate our strengths. High tech armies cannot rely on own technological advantages as potential opponents can and will use low tech methods to defeat or lessen advantages. This means that tactics must evolve.

Small Wars

Osirak raid

After 1973, the S-125 complexes were used by both Iraqis and Iranians in 1980-1988 war but there is not a lot of documents available. The use of Air Forces on both sides was primarily on the front line with sporadic attack deep into the enemy territory such as Iranian Air Force attempt to bomb Osirak nuclear reactor, located near Baghdad. To protect the reactor, Iraqis deployed S-125 missile battalions and anti-aircraft artillery around the nuclear complex. However, the reactor attack has been performed by the Israelis because of the fear that Iraqi dictator Sadam Hussein may pursue the nuclear Weapons.

Israeli Air Force launched one of the most daring attack in the history of air warfare. The attack squadron consisted of eight F-16As, each with two unguided Mark-84 2,000-pound delay-action bombs. A flight of six F-15As was assigned to the operation to provide fighter support. The F-16 pilots were Ze'ev Raz, Amos Yadlin, Dobbi Yaffe, Hagai Katz, Amir Nachumi, Iftach Spector, Relik Shafir, and Ilan Ramon. Raz led the attack, was later decorated by the Chief of Staff for his leadership. Ramon, who was the youngest pilot to participate in the operation, later became the first Israeli astronaut and died in the Columbia space shuttle disaster.

On 7 June 1981, at 15:55 local time (12:55 GMT), the operation was initiated. The Israeli planes left Etzion Airbase, flying unchallenged in Jordanian and Saudi airspace. To avoid detection, the Israeli pilots conversed in Saudi-accented Arabic while in Jordanian airspace and told Jordanian air controllers that they were a Saudi patrol that had gone off course. While flying over Saudi Arabia, they pretended to be Jordanians, using Jordanian radio signals and formations. The Israeli planes were so heavily loaded that the external fuel tanks that had been mounted on the planes were exhausted in-flight. The tanks were jettisoned over the Saudi desert.

On route to the target, the Israeli planes crossed the Gulf of Aqaba. Unknowingly, the squadron flew directly over the yacht of King Hussein of Jordan, who was vacationing in the Gulf at the time. Hussein witnessed the planes overfly his yacht and noticed their Israeli markings. Taking into account the location, heading, and armament of the jets, Hussein quickly deduced the

Iraqi reactor to be the most probable target. Hussein immediately contacted his government and ordered a warning to be sent to the Iraqis. However, due to a communication failure the message was never received, and the Israeli planes entered Iraqi airspace undetected.

Upon reaching Iraqi airspace the squadron split up, with two of the F-15s forming close escort to the F-16 squadron, and the remaining F-15s dispersing into Iraqi airspace as a diversion and ready back-up. The attack squadron descended to 30 m over the Iraqi desert, attempting to fly under the radar of the Iraqi defences.

At 18:35 local time (14:35 GMT), 20 km from the Osirak reactor complex, the F-16 formation climbed to 2,100 m and went into a 35-degree dive at 1,100 km/h, aimed at the reactor complex. At 1,100 m, the F-16s began releasing the Mark 84 bombs in pairs, at 5-second intervals. At least eight of the sixteen released bombs struck the containment dome of the reactor.

The crucial role in attack was the intelligence. Israeli meticulously studied the protection around the reactor and found the patterns in the air defence system which was used to plan the attack. It was later revealed that half an hour before the Israeli planes arrived, a group of Iraqi soldiers manning the surveillance radars had left their posts for an afternoon meal, turning off their radars. This was the window of opportunity to use to get the safe approach. The Israeli planes were still intercepted by Iraqi defences but managed to evade the remaining anti-aircraft fire. The squadron climbed to high altitude and started their return to Israel. The attack lasted less than two minutes.

Bekaa valley

One of the greatest air defence suppression engagements after the Yom Kippur War was the Bekaa valley battle (operation Mole Cricket 19), fought on June 9 1982 in the Lebanon Bekaa valley between Syrian air defence and Israeli Air Force. In this battle S-125 systems were not deployed however the more modern and mobile system KUB (SA-6) systems have been engaged and this battle cemented the future of air suppression and air defence tactics for the wars to come. This is also the first engagement with and extensive use of remotely piloted vehicles (RPV) later known as unmanned aerial vehicles or drones.

The IDF attack against the 19 Syrian SA-6 sites was the execution of a highly orchestrated, combined arms plan that stressed planning, intelligence,

training, surprise, command, control, and communications, and countless elements of Electronic Combat in a three-phased attack.

The overall plan for the Suppression of Enemy Air Defences (SEAD) was designed to take advantage of two Syrian air defence mistakes. The most fundamental mistake was the lack of movement by the missile batteries. The SA-6 was designed as a mobile SAM system, yet the Syrians had their SA-6 batteries dug in for over a year in the Bekaa clearly visible for Israeli air reconnaissance. This allowed the Israelis to pinpoint the precise location of each target. The second mistake was the lack of emission control by the Syrian SAM operators. The Syrians turned their radars on frequently, and often used more radars than required when practicing engagements. This allowed the Israelis to fingerprint or identify the exact radar frequencies used by the Syrians. The fingerprinting allowed for jamming operations and the targeting of anti-radiation missiles. Most of this information was the direct result of the Israeli prewar intelligence effort. For an extended period of time prior the Lebanon invasion. Israeli remotely piloted vehicles (RPVs) overflew the area defended by the Syrian SAMs and collected the intelligence which led to the development of the attack plan. The two workhorses of this effort were the UAV's Mastiff and the Scout. The Mastiffs contained a gyro-stabilized television and a high-resolution panoramic camera which proved extremely effective in photo-reconnaissance. The Scouts were configured for electronic intelligence and picked up the radar emissions which enabled the fingerprinting of the SAM radars. Both RPVs were capable of relaying their information to ground and airborne command posts for immediate analysis. But good intelligence and a good plan must be followed by training to make the most of the prewar effort.

The IDF conducted extensive northern border training exercises which were actually rehearsals for the upcoming invasion. These exercises, which were held for over 13 months, included rehearsal sorties against simulated SA-6 sites in the Negev desert. Countless rehearsals eliminated many of the problem areas that planners do not always foresee in coordinating an integrated plan. These rehearsals were intended to reduce some of the fog and friction of war for military leaders, soldiers, and aviators. The rehearsals also achieved a planned desensitization of the PLO and Syrians. Fearing that a real invasion was underway, the PLO and Syrians reacted to the first five northern border exercises. There was not a real response to the remaining rehearsals, nor the real thing.

Israel was able to achieve real surprise in their invasion because of Palestinian "alert fatigue" or "cry wolf" syndrome, because the PLO assumed they had developed a deterrent to an Israeli invasion, and because the Syrians assumed an attack against their SAM sites too risky. The IDF actually invaded on their ninth exercise and found no real resistance thanks to their planned desensitization. A second reason for their surprise was the PLO assumed they had a real deterrent to invasion. They incorrectly assumed their threatened massive rocket attacks against northern Israeli settlements and the threat of Syrian military reaction would deter. And finally, with the devastating success of the SA-6 against Israeli aircraft in the 1973 war, Syrians concluded the Israelis would consider an attack against the SAM sites too risky. With the element of surprise in hand, along with a good plan, precise intelligence, and with extensive training completed, Israel now looked to her military commanders to conduct the fight.

Israeli commanders proved that an effective command, control, and communications (C3) system is the essential ingredient to successfully integrate a combined arms effort, and that denial of C3 to the enemy will take a serious toll on battlefield effectiveness. C3 is the nervous system of a modern military force and the tactical commander is the brain. In the Israeli SEAD effort, the tactical commander received most of his information through an Israeli version of the Boeing 707 and from E-2C aircraft. The 707 served primarily as an electronic support measures (ESM) and electronic countermeasures (ECM) platform. ESM involves the gathering of communication and electronic intelligence. ECM primarily involves the jamming and deception of enemy communications. The E-2C served primarily as an airborne command post. With the facilities aboard these aircraft, the tactical commander was able to process real time intelligence, develop a true picture of the tactical situation, coordinate his offensive assets with the proper timing, monitor the attack in progress, and then immediately assess the effectiveness of the attack. Furthermore, the tactical commander was also able to coordinate the jamming and deception that so effectively disrupted Syrian defences. On the afternoon of 9 June 1982, the tactical commanders within this effective C3 system commenced their three-phase attack which emphasized electronic combat.

The first phase of the attack, deception, involved the stimulation of the Syrian radar systems. The initial drones over the target were probably a combination of Mastiffs and Scouts. These drones re-verified the locations of the SAM sites and their radar frequencies, and also served to stimulate the radars

into activity. The slow speed of the Mastiffs and Scouts probably did not generate any more than the usual amount of disinterest shown over the previous year. The large force of air-launched Samson’s and ground-launched Delilahs, though, did receive their full attention. These decoy drones more closely resemble the speed and appearance of attacking aircraft when viewed on a radar screen. The direction of the attack placed the afternoon sun directly behind the incoming drones, degrading Syrian optical guidance systems on the SAMs. This forced greater reliance on their radar and increased vulnerability to anti-radiation missiles. The Syrians took the bait as expected. They showed poor target discrimination and firing discipline. They launched most of their available SAMs against the incoming drones. When the Boeing 707's ESM sensors confirmed the Syrian radars were fully activated and the SAM batteries were in their first reload cycle, the next phase of the attack was initiated. During this phase, Syrian missile destroyed a number of drones.

The second phase integrated many activities into an extremely effective harassment and suppression effort. The 707 now used its ECM capabilities and began to jam Syrian radar frequencies, blinding their missiles. The 707 was augmented with ground-based jammers and with other airborne jammers located on CH-53 helicopters and on the attacking aircraft. Artillery fire, with their aim adjusted by the TV pictures from the Mastiff, now harassed the SAM operators. The sites were shelled with 105 mm howitzer rounds and with Ze'ev missiles, carrying terminally guided cluster munitions. Chaff-dispensing rockets further obscured the radar picture for the Syrian radar operators. With radar screens blinded by jamming and chaff, and operators harassed by artillery fire, the Israeli Air Force (IAF) went to work. F-4s launched their Shrike and Standard anti-radiation missiles which homed in on the radar signals emitted by the SAM radars, destroying the radar, antennas. After this attack, the tactical commander was able to determine how many, and exactly which SAM sites remained effective. Armed with the information fed to him via RPV television pictures and the ESM assets aboard the 707, he then commenced the final phase of the attack.

The final phase of the attack destroyed the remaining pieces of the Syrian SAM sites in the Bekaa valley. The E-2C airborne warning and control aircraft now guided Israeli Air Force F-16s, A-4s, and Kfir C-2s. The E-2C vectored them through the undefended areas for the follow-on attacks against the surviving radar vans and SA-6 missile launchers. Using standoff munitions, cluster bomb units, and general-purpose bombs, the Israeli aircraft simultaneously attacked from multiple directions after a low-level ingress. The

Syrians continued to launch missiles from the now radarless sites in a futile effort to defend themselves. Lacking acquisition and target tracking capability without their radars, the missiles were ineffective against the maneuvering aircraft. The Syrians also tried to obscure the SAM sites with smoke to prevent the use of laser guided weapons by the Israelis. But the fires were started too late to create enough smoke for obscuration. In fact, this tactic only made target acquisition for the aviators much easier by highlighting the exact locations of the sites. Finally, the Syrian operators turned the remaining radars off to avoid destruction, the ultimate act of futility. Losing the battle on the ground, the Syrians launched Mig-21 and Mig-23 aircraft to intercept and repel Israeli aircraft.

The Syrians responded by launching about 100 fighter aircraft to stop the attacks. Intercepting IAF pilots relied frequently on VHF radio, in hopes of preserving their tactical communications and links to the command post. Selective airborne communications jamming disrupted the airwaves for the MiG-21s and MiG-23s and cut them off from ground control, making them vulnerable to AWACS-directed attacks from the Israeli F-15s and F-16s.

The IAF positioned RPVs over three major airfields in Syria to report when and how many Syrian aircraft were taking off. The data was transmitted to the E-2Cs. The IAF took advantage of the fact that the MiGs had only nose and tail alert radar systems and no side warnings or look-up and look-down systems, by jamming the GCI communications net. E-2Cs guided the Israeli aircraft into positions that enabled them to attack the Syrian aircraft from the side, where the latter would have no warning. Because of the jamming, the Syrians GCI controllers could not direct their pilots toward the incoming Israeli aircraft. The Sparrow missiles attacked at speeds of Mach 3.5 at ranges of 22 to 40 km (14 to 25 miles), which meant that they were not only outside the Syrians' radar range but also outside their visual range. The Sidewinders' "head-on" capabilities at close range gave the Israelis firepower advantage. Near 4:00 PM, with fourteen batteries destroyed and an hour left until dark, Israelis decided to call off the operation, assuming the optimal result had been achieved and that the Syrians would move more SAMs into place the next day. The operation was stopped shortly after 4:00 PM.

There is a lot of controversy about the results of the battle and western and soviet bloc press information was contradictory. The Soviet military newspaper Krasnaya Zvezda announced that "sixty-seven Israeli aircraft,

including modern US-made F-15 and F-16 fighters, were downed" in the fighting. The newspaper also reported a meeting with a Syrian airman who recounted an engagement in which he shot down an Israeli F-15: "The victory had not been easy; the enemy had been subtle". Even within Soviet ranks, these claims met with great skepticism. In 1991, Israeli commander during the war, general Ivry met a Czech general who had been serving in Moscow in 1982. He told Ivry that the operation made the Soviets understand that Western technology was superior to theirs and that in his view, the blow to the Beqaa Valley SAMs was an impetus to Glasnost and the Soviet Union's collapse. This may be overestimated but one is for sure and that the Syrians made crucial mistakes in the tactical use of the air defence systems which Israelis exploited in the full scale.

Angolan Border Wars

During the South African border war with Angola, there were numerous engagements of South African air forces attacking the Angolan and Cuban positions. The Angolan forces with the help of the Soviet instructors developed an extensive anti-aircraft system over time, which included guns (20 mm, 23 mm, 37 mm, 57 mm and even some larger calibres) and a full range of surface-to-air missiles. The latter included the SA-7, SA-14 and SA-16 shoulder-launched missiles; the SA-9 and SA-13 infra-red homing missiles mounted on armoured vehicles; the self-propelled SA-8 medium-range system (the first used outside the major Warsaw Pact forces) and the longer-ranged transportable SA-6 and static SA-3. The weapons were backed up by a comprehensive radar system. All in all the Angolan air defence system in the second half of the 1980s was very similar to that encountered by the allied forces in Iraq in 1991. The SAAF was, however, generally able to continue to operate effectively, bypassing the air defences or conducting air defence suppression strikes. Several aircraft were lost to SAMs. Most of the SAAF's aircraft losses, however, were suffered by helicopters and Impalas flying low, and most of them were lost to light anti-aircraft guns.

During the 15 years of bush war between 1979 and 1989, the SAAF lost a total of 22 aircraft as a direct result of enemy action. This period included operations in Rhodesia, Mocambique, South West Africa and Namibia. During the same time many aircraft was struck by enemy fire but landed safely again. Most of these were hit by either SA-3, SA-7 and SA-9, some small arms fire and of course Arthur Piercy suffered a hit by an AA-8 fire from a Mig-23.

Operation Desert Storm

At the start of the Persian Gulf War, U.S. and allied aircraft rained tons of bombs and missiles on Iraq, rendering its air defence system inoperative for the rest of the conflict.

A USAF F-16 (serial 87-257) was shot down on January 19, 1991, during Operation Desert Storm. The aircraft was struck by an SA-3 just south of Baghdad. The pilot, Major Jeffrey Scott Tice, ejected safely but became a POW as the ejection took place over Iraq. It was the 8th combat loss and the first daylight raid over Baghdad (**Figure 6-4**).

On the opening night of Desert Storm, on 17 January 1991, a B-52G was damaged by a missile. Different versions of this engagement are told. It could have been a S-125 or a 2K12 Kub while other versions report a MiG-29 allegedly fired a Vympel R-27R missile and damaged the B-52G. However, the U.S. Air Force disputes these claims, stating the bomber was actually hit by friendly fire, an AGM-88 High-speed, Anti-Radiation Missile (HARM) that homed on the fire-control radar of the B-52's tail gun; the jet was subsequently renamed In HARM's Way. Shortly following this incident, General George Lee Butler announced that the gunner position on B-52 crews would be eliminated, and the gun turrets permanently deactivated, commencing on 1 October 1991.

Despite the intensive bombing, President Saddam Hussein's extensive network against air attack was never really obliterated during the Gulf War. A substantial portion of it survived the pummeling by allied aircraft, which had been intent on shutting the system down, not blowing it to pieces.

Saddam's main air defence command centers, located deep underground in hardened bunkers, escaped elimination. And numerous above-ground antennas and radar facilities that were struck have since been repaired from large stocks of spare parts that Iraq had on hand before the war, experts say. The Iraqis also have shown some resourcefulness in obtaining parts from abroad, despite the sanctions, and have gone on to establish new missile sites.

Much of the Iraqis equipment is the same used by former Warsaw Pact countries and there were a lot of spare parts out there now on the open market that the Iraqis could get. Still, for all its resiliency, the Iraqi system suffers from significant shortcomings, including reliance on outdated Soviet-era technology, a

lack of airborne monitoring equipment and a loss of foreign technical assistance.

Iraq's air defence network was patterned after the Soviet model and built largely by the French. Known as KARI (the French name for Iraq, spelled backward), its hub is in Baghdad. The network branches into several regional operations centers, which in turn control tracking centers, aircraft interceptors, surface-to-air missile batteries and antiaircraft guns in their respective regions. The Iraqi system contained considerable redundancy, with one center able to pass control to another if damaged. There is some overlapping coverage by radar dishes. And hundreds of mobile antiaircraft missile launchers can shift locations to set traps for enemy aircraft.

As per US analyses, the Iraqis stopped operating their air defences after the first few days of fighting in 1991 to spare what they could, As long as they weren't challenging allied aircraft, they were not targeted. As a result, their losses were reduced, and they emerged with a large part of their system intact.


Figure 6-1: Egyptian SA-3 on the firing position
(Source: Egyptian war museum)


Figure 6-2: Downed Israeli Mirage 3
(Source: Egyptian war museum)

Figure 6-3: Wing of downed Israeli Skyhawk
(Source: Egyptian war museum)

Figure 6-4: Tail section of downed USAF F-16 during the operation "Desert Storm"
(Source: Wikipedia)

Chapter Seven

The First Stealth Program

Air war over North Vietnam and the Yom Kippur War 1973, in which Israeli Air Forces suffered heavy losses inflicted by Soviet made anti-aircraft missile systems, were responsible for the Defense Advanced Research Projects Agency (DARPA) initiating conceptual studies into developing a manned aircraft with a sufficiently low RCS to defeat modern air-defense systems. Consequently, in 1974 the Tactical Technology Office (TTO) at DARPA requested submissions from the leading defense contractors Northrop, McDonnell Douglas, General Dynamics, Fairchild, and Grumman, under the code name Project Harvey (derived from an old movie and “featuring” an invisible rabbit named Harvey), addressing two considerations:

1. What were the signature thresholds that an aircraft would need to achieve to become essentially undetectable at an operationally useful range?
2. Secondly, did the relevant companies possess the capabilities to design and produce an aircraft with the necessary low signatures?

Fairchild and Grumman declined the invitation to participate, while General Dynamics emphasized the continued need for electronic countermeasures. However, the submissions from McDonnell Douglas and Northrop demonstrated both a grasp of the problem and a degree of technical capability for developing an aircraft with a reduced signature. Consequently, both companies were awarded contracts for the further studies during the closing months of 1974.

Radar experts from the Hughes Aircraft Company were also involved, their role being to identify and verify appropriate RCS thresholds. At this early stage the studies were only classified as “Confidential.” Bill Elsner was the primary USAF technical expert on the program, and by the beginning of 1975 McDonnell Douglas had identified likely RCS thresholds that could produce an operational advantage. In the spring, these were confirmed by Hughes and were established by DARPA as goals for the program. DARPA then challenged the participants to find ways of achieving them.

Lockheed had not been one of the five original companies approached by

DARPA, simply because it had not produced a fighter for nearly ten years and because majority of the works were devoted to the secret CIA programs. Lockheed was also plagued by international bribery scandal, involving some of the top management people and that scandal threatened the very existence of the company. Whilst networking his contacts at the Pentagon and Wright-Patterson Air Force Base (AFB), Ed Martin, Lockheed California Company's Director for Science and Engineering, was made aware of the study. He flagged this to Ben Rich (**Figure 7-2**), who at this time was deputy to the Skunk Works legendary president Clarence L. “Kelly” Johnson (**Figure 7-1**). The two men then briefed Johnson, who in turn obtained a letter from the Central Intelligence Agency (CIA), granting the Skunk Works permission to discuss with DARPA the low observable (LO) characteristics of their earlier A-12 and D-21 drone program.

Rich and Martin presented this data to Ken Perko and Dr George Heilmeier, the head of DARPA, and formally requested entry into the competition. However, Heilmeier explained that two $100,000 contracts had already been awarded and there was no more cash available. Drawing upon his negotiation skills, Rich convinced the DARPA boss to allow Lockheed into the competition without a government contract – a move that ultimately paid a handsome dividend down the road. The Skunk Works team was then given access to technical reports already provided to the other participants, and the first step that would culminate in a revolutionary aircraft was taken.

Hopeless Diamond and Have Blue

The F-117 was the first warplane to be specifically designed from the outset for low radar observability. The Lockheed Advanced Development Company (better known as “Skunk Works”) began working on Stealth as far back as the late 1950s. Low radar observability had played a role in the design of the A-12/YF-12/SR-71 series of Mach 3+ aircraft.

During 1975, Skunk Works engineers began working on an aircraft which would have a greatly reduced radar cross-section that would make it all-but-invisible to enemy radar but would nevertheless still be able to fly and carry out its combat mission.

We already saw in Chapter 2 the stealth theory and the influence of the work of soviet scientist Pyotr Ufimtsev's on the subject. Denys Overholser (**Figure 7-3**) was an exceptional Skunk Works mathematician and radar specialist. One day in April 1975 he visited Ben Rich in his office and presented him with, as he believed, the Rosetta Stone breakthrough for stealth technology. The material that he showed to Rich would make an attack airplane so difficult to detect that it would be invulnerable against the most advanced radar systems yet invented, and survivable even against the most heavily defended targets in the world.

Overholser had discovered that material deep inside a long, dense technical paper on radar written by Pyotr Ufimtsev nine years earlier. The paper was only recently been translated by the Air Force Foreign Technology Division from the original Russian publication. In Overholser own words, the paper was so obtuse and impenetrable that only a geek of the geeks would have dig through it all and find the right spot. As Overholser explained to Rich, Ufimtsev had revisited a century-old set of formulas derived by Scottish physicist James Clerk Maxwell and later refined by the German electromagnetics expert Arnold Johannes Sommerfeld. These calculations predicted the manner in which a given geometric configuration would reflect electromagnetic radiation. Ufimtsev had taken this early work a step further.

Overholser found in Ufimtsev's book how to accurately calculate radar cross sections across the surface of the wing and at the edge of the wing and put together these two calculations for an accurate total set. Radar cross section

calculations were, as Ben Rich mentioned in his autobiography, "branch of medieval alchemy as far as the non-initiated were concerned". Making big objects appear tiny on a radar screen was probably the most complicated, frustrating, and difficult part of modern warplane designing. A radar beam is an electromagnetic field, and the amount of energy reflected back from the target determines its visibility on radar. For example, RCS of USAF B-52, was the equivalent of a flying dairy barn when viewed from the side on radar. F-15 tactical fighter was as big as a two-story house. It was questionable whether the F-15 or the newer B-70 bomber would be able to survive the ever-improving Soviet defensive net.

The F-111 tactical fighter-bomber, using terrain-following radar to fly close to the ground and “hide” in ground clutter, wouldn’t survive either. Operating mostly at night, the airplane’s radar kept it from hitting mountains, but as we discovered above North Vietnam, it also acted like an alarm to North Vietnam air defenses which was able to pick up the F-111 radar emission from few hundred kilometers away. The Skunk Works desperately needed new answers, and Ufimtsev had provided those answers with an “industrial-strength” theory that now made it possible to accurately calculate the lowest possible radar cross section and achieve levels of stealthiness never before imagined.

In his book, Ufimtsev presented mathematical equations which served as a base for how to create computer software to accurately calculate the radar cross section of a given configuration, as long as it’s in two dimensions. In his own words, Overholser explained to Rich that they can break down an airplane surface into thousands of flat triangular shapes, add up their individual radar signatures, and get a precise total of the radar cross section.

Two dimensions flat plates were the maximum that computers of the day can handle. Computers were not yet sufficiently powerful in storage and memory capacity to allow for three-dimensional designs, or rounded shapes, which demanded enormous numbers of additional calculations. The new generation of supercomputers, which can compute a billion bits of information in a second, is the reason why the B-2 bomber or F-22 fighter, with its rounded surfaces, were designed entirely by computer computations.

Overholser’s idea was to compute the radar cross section of an airplane by dividing it into a series of flat triangles. Each triangle had three separate points and required individual calculations for each point by utilizing Ufimtsev’s

calculations. The result we called “faceting” - creating a three-dimensional airplane design out of a collection of flat sheets or panels, similar to cutting a diamond into sharp-edged slices.

The Skunk Works would be the first to try to design an airplane composed entirely of flat, angular surfaces. Overholser estimated that he would need six months to create his computer software based on Ufimtsev’s formula. All he got form Rich was a half of that.

The Skunk Works had the RCS-prediction software was called "Echo 1". This was leap ahead, in the time where most of the engineers in the design bureaus worldwide used slide ruler for calculations. As tests with the program proceeded, it became apparent that edge calculations by the program were incorrect due to diffraction. What was necessary to go forward and solve the diffraction problem was Ufimtsev theory. Overholser incorporated elements of Ufimtsev's work to refine the software and he and his old mentor, Bill Schroeder, who had come out of retirement in his eighties to help him after serving as Skunk Works mathematician and radar specialist for many years, delivered the first results in only five weeks. The game plan was for Overholser to design the optimum low observable shape on his computer, then to continue work to refine the software. Echo 1 allowed the team to quickly decide which of the 20 possible designs were optimal, finally settling on the faceted delta-wing design. However, many within the division were skeptical of the shape, giving rise to the name "Hopeless Diamond" (**Figure 7-4**) because they thought it will never fly. It was Kelly Johnson who was the one who gave the name in one conversation with Ben Rich.

The technique they came up with was known as faceting in which the ordinarily smooth surface of the airframe is broken up into a series of trapezoidal-or-triangular flat surfaces arranged in such a way that the vast majority of the radar incident on the aircraft from a source will be scattered away from the aircraft at odd angles, leaving very little to be reflected directly back into the receiver. An additional reduction in radar cross-section was to be obtained by covering the entire surface of the aircraft with radar absorbent material (RAM).

One of the disadvantages involved in the use of faceting on aerodynamic surfaces was that it tended to produce an inherently unstable aircraft in all 3 axes - pitch, roll, and yaw.

In early 1977, Lockheed received a contract from the Defense Advanced Research Projects Agency (DARPA) for the construction of two 60-percent scale flyable test aircraft under a project named "Have Blue" (**Figure 7-5**). The name "Have Blue" seems to have no specific meaning - probably having been chosen at random from an approved list of secret project names.

Shortly after the "Have Blue" contract was let, the project was transferred over to Air Force System Command control and became highly “black” with all information about it being highly-classified and restricted to those with a "need-to-know". Outside of a few people at Lockheed and the Defense Department, no one knew "Have Blue" even existed. The 2 "Have Blue" aircraft were built at Lockheed in only a few months. The first example was intended to evaluate the type's flying characteristics, whereas the second was to evaluate the radar signature. In order to save sometime and some money, existing off-the-shelf components were used where feasible.

The engines were a pair of standard production non-afterburning General Electric J85s mounted in enclosures sitting atop the wings. The main landing gear was taken from a Fairchild Republic A-10, and fly-by-wire components were scavenged from an F-16. The instrumentation and the ejector seat were taken from a Northrop F-5.

The "Have Blue" aircraft had the same general shape as that which would later become familiar with theF-117A, except that the twin rudders were located forward of the exhaust ejectors and were angled inward rather than outward. The inward cant was about 30 degrees. The leading edge of the semi-delta wing was swept back at 72.5 degrees. The wing featured 2 inboard trailing edge elevons for pitch and roll control 4 spoilers (2 on top of the wing and 2 on the bottom) were mounted just forward of the elevons. There were no flaps or speed brakes. The wing trailing edge was less deeply notched than that of the F-117. A single cockpit with an ejector seat was provided.

The "Have Blue" aircraft employed V-type windshields (similar to those of the F-102/F-106). No weapons bay nor any sort of tactical equipment at all was fitted. The "Have Blue" aircraft were equipped with fly-by-wire (FBW) flight controls adapted from the F-16 system. However, the system had to be modified to handle an aircraft that was unstable about all 3 axes (the F-16 is unstable only about the pitch axis).

The problem of designing a stealthy system for airspeed measurement had not yet been solved. The aircraft were equipped with a conventional pitot tube which was retracted during testing for radar reflections. The inertial navigation system provided enough speed data for test purposes when the probe was retracted.

Two prototypes were built at a cost of $37 million for both aircraft. Lockheed workers assembled the two "Have Blue" aircraft in a cordoned-off area in Lockheed's Plant 10 facility housed at the USAF Plant 42 in Palmdale, California. Neither aircraft ever received an official DoD designation, nor did they get a USAF serial number. However, Lockheed did give the aircraft its own manufacturer's serial numbers - 1001 and 1002, meaning Plant 10/ aircraft numbers 01 and 02.

The first example (1001) was finished in November of 1977. In order to keep the project away from prying eyes, the "Have Blue" prototype was shipped out to the Groom Lake Test Facility in Nevada in high secrecy for the test flights. Groom Lake is located in a particularly remote area of the Nellis test range complex and is a good location for the testing of secret aircraft. A camouflage paint scheme was applied to make it hard for unwanted observers at Groom Lake to determine the aircraft's shape.

The first flight of the "Have Blue" took place in January or February of 1978 (the exact date is still classified), veteran Lockheed test pilot William M. Bill Park being at the controls. At an early stage, Bill Park was assisted in the flight test program by Lt. Col. Norman Kenneth (Ken) Dyson of the USAF. Flight test of the "Have Blue" initially went fairly smoothly and the fly-by-wire system functioned well. The landing speed was quite high (160 knots) as expected because of the lack of flaps or speed brakes.

Figure 7-5: Have Blue (Source: Pinterest)

However, on May 4, 1978, "Have Blue" prototype number 1001 was landing after a routine test flight when it hit the ground excessively hard, jamming the right main landing gear in a semi-retracted position. Pilot Bill Park pulled the aircraft back into the air and repeatedly tried to shake the gear back down again. After his third attempt failed, he was ordered to take the aircraft up to10,000 feet and eject. Park ejected successfully, but he hit his head and was knocked unconscious. Since he was unable to control his parachute during descent or landing, his back was severely injured on impact. He survived but was forced to retire from flying. The "Have Blue" aircraft was destroyed in the crash and the

wreckage secretly buried somewhere on the Nellis test range complex.

Have Blue 1002 arrived at Groom Lake shortly after the loss of number 01. It took to the air for the first time in June of 1978, Lt. Col. Ken Dyson being at the controls. From mid-1978 until early 1979, Lt. Col. Dyson flew more than 65 test sorties, testing the response of the aircraft to various types of radar threats. "Have Blue" prototype 1002 proved to be essentially undetectable by all airborne radars except the Boeing E-3 AWACS, which could only acquire the aircraft at short ranges. Most ground-based missile tracking radars could detect the "Have Blue" only after it was well inside the minimum range for the surface-to-air missiles with which they were associated. Neither ground-based radars nor air-to-air missile guidance radars could lock onto the aircraft.

It was found that the best tactic to avoid radar detection was to approach the radar site head-on, presenting the Have Blue's small nose-on signature. The application of the RAM was rather tricky, and ground crews had to be careful to seal all joints thoroughly before each flight.

RAM came in linoleum-like sheets which were cut to shape and bonded to the skin to cover large areas. Doors and access panels had to be carefully checked and adjusted for a tight fit between flights. All gaps had to be filled in with conductive tape and then covered over with RAM. Paint-type RAM was available, but it had to be built up by hand coat-by-coat. Even the gaps around the canopy and the fuel-filler door had to be filled with paint-type RAM before each flight. Ground crews had to even make sure that all surface screws were completely tight, since even one loose screw for an access panel could make the aircraft extremely visible during radar signature tests.

“Have Blue” number 1002 was lost in July 1979. During its 52nd flight with Lt. Col. Dyson at the controls, one of its J85 engines caught fire. The subsequent intense fire burned through the hydraulic fluid lines, forcing Lt. Col. Dyson was to eject. "Have Blue" #1002 was a total loss and consequently also secretly buried on the Nellis test range complex. No further "Have Blue" aircraft were built since the general concept had been proven.

F-117 development and testing

The F-117A stealth bomber had the same general configuration of the "Have Blue" test aircraft but was much larger and heavier and was provided with an offensive military capability (**Figure 7-6**). The structure of the F-117A is constructed mainly of aluminum with some titanium being used in the engine and in the exhaust systems. The main facets of the outer skin are separately fastened to a rather complex skeletal frame. Since the accurate shaping and placement of these facets is critical to achieving a low radar cross-section (RCS), production tooling had to be 10 times more precise than the tooling used to build conventional aircraft (**Figure 7-7**).

The entire outer skin of the F-117A is covered by radar absorption material (RAM). The exact composition of the RAM is classified, but it is believed to consist of a matrix of magnetic iron particles held in place by a polymer binder. Originally, RAM came in large flexible sheets and was bonded to a metal wire mesh, which was in turn glued to the airframe of the F-117A. Later when the aircraft entered service, the Air Force built a special facility for the application of the RAM. In order to provide for uniform and accurate application - as well as to prevent people from coming into contact with the highly toxic solvents which make the RAM liquid - the process is completely automated.

During the application of the RAM, the F-117A is supported spit-like and slowly turned as the RAM is sprayed on by computer-controlled nozzles. Minor touch-ups are made in the field using a hand-held spray gun.

The engines powering the F-117A are a pair of non-afterburning General Electric F404-GE-F1D2 turbofans, derivatives of the afterburning F404-GE-400 turbofans that power the McDonnell Douglas F/A-18 Hornet. They are housed in broad nacelles attached to the sides of the angular fuselage. The General Electric turbofans are fed by a pair of air intakes (one on each side of the fuselage). Two gratings with rectangular openings cover each intake (**Figure 7-8**). The purpose of these gratings is to prevent radar waves from traveling down the intake ducts and reaching the whirling blades of the turbofans, which would tend to produce large echoes. This works because the spacing between the grids on the grating are smaller than the wavelengths of most radars. The grating is covered with RAM which helps reduce the reflections even further.

The small fraction of incident radar energy which does pass through the grating is absorbed by RAM mounted inside the duct. Unfortunately, these gratings also restrict airflow to the engines. So, a large blow-in door is fitted atop each engine nacelle to increase airflow to the engine during taxiing, takeoffs, or low-speed flight (**Figure 7-9**). Ice buildup on the intake gratings is a persistent problem which tends to clog the rectangular openings and restricts the airflow even further. In order to clear the ice, the F-117 employs a electrical heating system to remove ice during flight. A light on either side of the fuselage illuminates the intake covers, enabling the pilot to watch the de-icing operation during night flights.

One of the more unusual aspects of the F-117 is its engine exhaust system. Like the air inlets, the exhaust outlets are mounted atop the wing chord plane - one on each side of the centerline. The engine exhausts are narrow and wide and are designed to present as low an infrared signature as possible and mask the rear of the engine from radar illumination from the back. The exhaust ducts are round at the rear of the turbofans but are flattened out and become flume-like by the time that they reach the front of the narrow-slotted exhaust outlets at the rear of the fuselage. At the end of each of the narrow-slotted exhaust ducts, there are 12 grated openings, each being about 6 inches square. These grated openings help reduce unwanted radar reflection from the rear as well as providing additional structural strength to the exhaust ducts. The exhaust gratings are shielded from the rear and from the bottom by theF-117's platypus-bill-shaped rear fuselage section.

The extreme rear edge of the aircraft behind the exhaust slot is covered with heat-reflecting tiles. These ceramic tiles help to keep the rear of the aircraft cool since they tend to reflect the infrared radiation emitted from the exhaust, rather than absorbing it as metals tend to do. The bypass air from the engine is also used to help cool down the entire metal structure of the rear of the aircraft.

The exhaust system is complex, incorporating sliding elements and quartz tiles to accommodate heat expansion without changing shape. Although the system works fairly well, Lockheed has reported that the design of this exhaust system was the single most difficult item in the entire F-117 project.

A typical fighter has a head-on RCS of about 5 square meters, which is technical language for saying that it seems as large on radar as a perfectly-reflective sphere of the same cross-sectional area. However, if critical flat

surfaces or whirling turbine blades happen to be exposed to the radar, the RCS can be much larger. Reportedly, the combination of faceting and the application of RAM gives the F-117A an effective radar cross-section of somewhere between 0.01 and 0.001 square meters (**Figure 7-10**). That makes the F-117A appear to be no larger than a small bird on a radar screen. This means that a typical radar will not be able to detect an F-117A at a range any greater than 8-16 miles (**Figure 7-11**).

Figure 7-11: F-117 RCS for monostatic and bistatic dispersion
(Source: Harakteristiki radiolokacionih Zametnosti Letalnih Aparatov)

Directional stability and control of the F-117A is provided by a pair of all-flying tails mounted on the aircraft's central spine and oriented in a "V" arrangement, reminiscent of the tail of the Beechcraft Bonanza. Unlike most V-tails, however, they have no pitch-control function. Each vertical tail consists of a fixed stub and an all-flying rudder which pivots around a fixed shaft. The hinge line between stub and moveable tail is Z-shaped rather than straight, in accord with the stealth principle of the avoidance of any straight edges.

Both the fixed stub and the all-flying rudder are faceted to further reduce radar reflectivity. On the "Have Blue" test aircraft, the vertical tails were mounted further outboard on the wings and were canted inward rather than outward. The purpose of the inward-canted vertical tails on the "Have Blue" was to shield the upward-facing platypus exhaust nozzles from infrared detectors above the aircraft (**Figure 7-12**). In practice, however, these tails tended to act as reflectors for infrared radiation, bouncing the rays toward the ground and making the aircraft more visible from below.

Originally, the basic stealth design philosophy was to have the lowest observability from the bottom and from the front, with the upper hemisphere having less stringent requirements.

Consequently, on the F-117A aircraft, the tails were moved back further on the fuselage so that they are no longer directly over the exhaust. In addition, the "Have Blue" tails were in effect mounted on twin booms which were a structurally inefficient arrangement.

The leading-edge wing sweeps on the "Have Blue" was 72.5 degrees, and the resulting low aspect ratio gave a rather poor payload-range performance. To improve the performance, the wing sweep was reduced to 67.5 degrees on the F-117A. The flying surfaces on the F-117A consist of 4 elevons on the wing

trailing edge (2 inboard and 2 outboard) and 2 all-flying rudders mounted in a "V" arrangement on the rear fuselage. The elevons and the rudder are all faceted to reduce their radar signature. And the hinge lines between the wings and the elevons sealed with flexible RAM. The 4 elevons can deflect upward or downward by 60 degrees, and the rudders can deflect 30 degrees left or right. The elevons act in the pitch and roll axes whereas the rudders act in the yaw axis. The angle-of-attack during landing is about 9 degrees. The elevons do not double as flaps, which makes the landing speed of the F-117A rather high.

The "Have Blue" cockpit canopy windshield had a center bow, reminiscent of that of theF-102/F-106 interceptor. The F-117A replaced this windshield with a center flat panel since a heads-up display would not work very well with a center bow blocking the view. This resulted in a change in the shape of the nose to a steep downward-sloping section for good downward visibility with a sharp, pyramidal-shaped nose cap for aerodynamics and stealth. This change made the F-117 slightly more observable by radar than the "Have Blue".

The cockpit of the F-117 is covered by a large and heavy hood-like canopy with 5 separate flat transparencies (one on either side and 3 in front) (**Figure 7-13**). The visibility from the cockpit is rather limited upward, downward, and to the rear. The canopy opens to the rear and has serrated edges in order to limit the radar reflectivity of the joint between canopy and fuselage when the canopy is closed. The 5 flat transparent panels are specially treated to further reduce the aircraft's RCS. The windshield is coated with a special gold film layer to prevent the pilot's helmet from being detected by radar. This was found to be an important problem during early tests.

The pilot sits on a McDonnell Douglas ACES II ejector seat - the same type of seat fitted to the F-15C/D. The cockpit is equipped with a Heads-Up Display (HUD). The main control panel has two 5-inch CRTs, while the main FLIR/DLIRCRT had a 12-inch screen (**Figure 7-14**). For nighttime operations in clear weather at low altitudes, the aircraft is primarily flow by using the FLIR/DLIR CRT. The F-117A - like the "Have Blue" before it is unstable about all 3 axes and requires a fly-by-wire system in order to be able to fly at all. The fly-by-wire system is similar to that in the F-16 and is quadruply - redundant. There are 4 independent channels which each control the same function. The signals from each of the channels are constantly being compared with each other. And if one signal is found to differ from the other three, its channel is assumed to have "failed" and is automatically shut down. In the unlikely event that all 4

channels manage to fail at the same time, the aircraft cannot be flown, and the pilot would be forced to eject.

Since the aircraft cannot use any sort of radar navigation system, the fly-by-wire system relies on information about airspeed and angle-of-attack from 4 individual static pitot probes of diamond section with pyramid-like tips mounted in the extreme nose. Each of the 4-sided pitot heads have tiny holes on each facet. And differential readings from each hole provide air speed, pitch and yaw information to the flight control system. The design of these 4 nose sensors - plus the requirement that they not produce any unwanted radar reflections was one of the more difficult engineering problems the Lockheed team had to solve.

The F-117A also differed from the "Have Blue" in having a weapons bay. Since external hardpoints for bombs or fuel tanks are taboo for a stealth attack aircraft, all stores must be carried internally. The weapons bay is located in the belly on the centerline. It has 2 wells, each covered by an inboard-opening door. The outer edges of the weapons bay doors have serrated edges that are designed to reduce the radar reflection from the joint between the doors and the fuselage belly. The weapons bay can accompany up to 5,000 pounds of ordinance (2,500 pounds in each well). Some of the loads accommodated in the F-117A's weapons bay include 2 laser-guided MK84 2,000-pound bombs, 2 laser-guided GBU-10 Paveway II 2,000-pound bombs, 2 laser-guided GBU-12 Paveway II 500-pound bombs, 2 laser-guided GBU-27 Paveway III 2,000-pound bombs, 2 BLU 109 deep-penetration bombs, or 2 AGM 130s. The GBU-10 Paveway II laser-guided bomb consists of a special nose and tail section attached to a standard 2,000-pound Mk 84 high-explosive bomb. The tail section of the bomb consists of a set of folding aerodynamic surfaces which permit the bomb to glide, whereas the nose section includes a laser light seeker, guidance electronics, and control fins.

The GBU-24 Paveway III is a more advanced version of the Paveway II with a larger tail surface and a more efficient guidance system which permits it to be used at lower altitudes and at greater distances from the target. The BLU-109 deep-penetration bomb has a forged casing of hardened steel which

permits it to pierce more than 6 feet of reinforced concrete before exploding. When dropped on softer targets, the BLU-109 can bury itself deep into the ground before exploding, destroying its target by sending earthquake-like shock waves rippling through the ground.

The F-117A can also carry up to 2 Mark 61 nuclear weapons although the aircraft does not actually have an assigned nuclear mission. For long-range ferry flights, fuel tanks can be installed in the weapons bays in the place of bombs. The F-117A has no air-to-air capability. Or at least none that has been announced to the general public. It has no radar, it does not carry internal cannon, and is not equipped to carry or launch air-to-air missiles. The F-117A can in principle launch an infrared homer provided the missile can be dropped from an extendable rack so that its seeker could acquire the target before launch.

The F-117A cannot rely on radar for navigation, weapons aiming, or weapons delivery because the transmission of a radar signal would tend to giveaway the location of the aircraft and hence defeat the whole purpose of stealth. For low-level navigation and weapons-aiming purposes, the F-117 aircraft is provided with forward-looking infrared (FLIR) and downward-looking infrared (DLIR) systems. Both systems are built by Texas Instruments.

The FLIR is mounted in a recess just ahead of the cockpit front windshield. It is located in a steerable turret containing a dual field of view sensor. When not in use, the FLIR is rotated 180 degrees to keep prevent debris from damaging the sensor. The DLIR sensor system is located in a recess mounted underneath the forward fuselage and to the right of the nose landing gear well. Both the FLIR and the DLIR recesses are covered by a RAM mesh screen to prevent unwanted radar reflections from the active elements. The edges of the recesses are serrated, with fasteners covered with RAM putty. The DLIR is provided with a bore-sighted laser for illuminating the target for attack by laser-guided weapons. Together, these systems form the infrared acquisition and designation system (IRADS).

The laser is embedded to the IRADS and is an integral part of the infrared system. The spot size of the laser on the ground is about 12-18 inches and is stabilized in position by the IRADS. A highly-accurate Inertial Navigation System (INS) backs up the sensors. This system uses an electrostatically-suspended gyro as the primary means of guidance. The INS guide the aircraft to the immediate target area and points the FLIR's wide-angle field-of-view toward the general location of the target.

As the aircraft approaches the target, the pilot monitors the view presented by the FLIR on the heads-up display screen. When the specific target is identified, the pilot switches to the narrow view on the FLIR and locks the

screen of the display onto the target. As the target disappears underneath the aircraft, control is handed over to the DLIR which acquires the target and continues to track it. When the pilot decides to attack, he releases a laser-guided Paveway bomb.

Approximately 7-10 seconds before bomb impact, the DLIR's laser is turned on and illuminates the target, and the bomb homes onto the reflected infrared laser light reflected from the target. Videotapes from the FLIR/DLIR displays that have been released to the public by the DOD have shown that the F-117A flying during a clear night can hit a target only one meter in size from an altitude of 25,000 feet.

A parachute braking system is provided since the lack of flaps makes the landing speed quite high (160 knots, or 185 mph). The braking parachute is housed behind split doors atop the rear fuselage. The braking chute is deployed as soon as the nose wheel makes contact with the runway. The parachute can also double as an emergency anti-spin device if needed.

An in-flight refueling receptacle is added behind the pilot's cockpit. A small light is mounted near the receptacle to guide the refueling boom operator in nighttime refueling operations. Mid-air refueling is one of the more difficult aspects of F-117A flight, since it is always done at night and the F-117A pilot's upward vision is blocked by the canopy so that he cannot actually see the boom of the refueling aircraft.

The landing gear is of the standard tricycle type with single wheels and tires that retract forward. The landing gear doors have serrated edges that help to reduce the radar cross-section. A set of retractable communications antenna are fitted to the upper fuselage just behind the pilot. These are deployed during day flights but are retracted for stealth missions at night. Detachable radar reflectors can be mounted on the fuselage sides so that local air traffic control can track the aircraft when it is not in stealth mode.

Some of the reports of the F-117A being tracked by radar during "Desert Storm" may have been due to the mounting of these reflectors. In 1991, persistent problems with the unorthodox exhaust system led to a decision to fit a new type of engine exhaust system involving the use of a new bottom side to the shelf-like extension over which the exhaust passes. The modification involves the use of new heat shields, better seals, new airflow paths, and new high-

temperature thermal protection at the edge of the exhaust system. Most of these changes were designed to improve the maintainability of the exhaust system, which had proven to be a persistent problem.

During the production run of the F-117A, the 2 metallic all-moving tail fins were replaced with ones made of graphite thermoplastic materials. This change resulted from the loss of one fin and rudder from a F-117 in 1987 during a flight test. The aircraft landed safely despite the loss of the fin. The retrofit program was interrupted by Persian Gulf deployment, so most of the F-117s deployed to Saudi Arabia had the original metallic tail fins. The cockpit of the F-117A has been recently updated and improved in accordance with advances in electronics and display technology. The original navigation system of the F-117A was the SPN/GEAS inertial navigation system. Later this was replaced by a ring laser gyro and a global positioning system receiver. To improve the pilot's situational awareness, a Honeywell color multi-function display was fitted which had the capability of integrating a Harris digital moving map. 2 cathode ray tube-based multifunction displays are used to call up digital maps, target photos, or target identification diagrams. A liquid crystal display data entry panel allows the pilot to select from 256 avionics functions. The new cockpit equipment is designed to minimize the chance of pilot disorientation at night time, which was suspected as the primary cause of 2 accidents involving operational F-117s.

In the early 1990s, auto throttles were added to provide the capability for arrival at a precise predetermined time over a target. This innovation was, however, not available in time for Desert Storm. The F-117A carries a 3-digit serial number on the tail. The numbers are assigned in sequence, beginning with "780" and ending with "844". Aircraft "780" through "784" were full-scale development (FSD) aircraft, whereas "785" through "844" were production aircraft. The presentation of these numbers on the tail of the F-117A is sort of unusual, since the serial numbers of Air Force aircraft are typically presented as a combination of the last 2 numbers of the fiscal year in which the aircraft was ordered, followed by the last 3 digits of the aircraft's USAF serial number.

The results of the "Have Blue" testing were sufficiently encouraging that William Perry, who was at that time Under-Secretary of Defense for Research and Engineering in the Carter Administration, urged the Air Force apply the technology to an operational aircraft.

During November of 1978, Lockheed was awarded a go-ahead contract to

begin full-scale development of the project. This was a Special Access (i.e., "black") program, and the code name 'senior Trend" was applied to the project. The 'senior Trend" aircraft came to be defined as a single-seat night strike fighter with no radar but with an electro-optic system for navigation and weapons delivery. No air-to-air capability was envisaged.

The first 5 “Senior Trend” aircraft built by Lockheed were to be pre-production full-scale development (FSD) aircraft. The 'senior Trend" aircraft had the same General configuration as the "Have Blue" test aircraft but was much larger and heavier. The engines were a pair of non-afterburning General Electric F404-GE-F1D2 turbofans. These were derivatives of the afterburning F404-GE-400 turbofans which power the McDonnell Douglas F/A-18 Hornet.

In early June of 1981, the first 'senior Trend" service test aircraft (tail number "780") was delivered to Groom Lake for testing. On June 18, 1981, Lockheed test pilot Harold C. “Hal” Farley made a successful first flight in number 780. During mid-1981 and early 1982, the other 4 FSD 'senior Trend" aircraft joined the program. They bore tail numbers "781" through "784" respectively.

The first production 'senior" Trend (#785) arrived at Groom Lake in April of 1982. It differed from the pre-production “Senior Trend” aircraft in having a pair of enlarged fin/rudder assemblies with 3 facets rather than just 2. Aircraft number "785" was ready for its first flight on April 20 with Lockheed test pilot Robert L. Ridenauer scheduled to make the first flight. However, unbeknownst to anyone, the fly-by-wire system had been hooked up incorrectly (pitch was yaw and vice versa). Upon liftoff, Ridenauer's plane immediately went out-of-control. Instead of the nose pitching up, it went horizontal. The aircraft went inverted and ended up traveling backwards through the air. Riedenauer had no time to eject, and the aircraft flew into the ground. Bob Riedenauer survived the crash but was severely injured and was forced to retire from flying.

The aircraft was damaged beyond repair. But some of its parts could be salvaged. Since this aircraft crashed prior to USAF/TAC acceptance, it was not counted in the production total. When it came time for the establishment of the first operational unit for the stealth bomber, the Air Force was faced with a problem. Groom Lake was too small to be useful as the base for an operational unit. In addition, there were security concerns because an operational unit based at Groom Lake would involve many more people who could now see things that they should not be seeing. Therefore, the USAF decided to build a new secret

base for the stealth bomber on the Tonopah Test Range which sits on the Northwestern corner of the Nellis complex. The facility is not perfect from a security standpoint since it is overlooked by public land and is 32 miles from the town of Tonopah itself. However, the security surrounding the Tonopah Test Range was so effective that the new base was not public-reported until 1985 after it had been operating for nearly 2 years.

The 4450th Tactical Group was secretly established as the initial operator of the stealth fighter. The cover for the 4450th was that it was a Nellis-based outfit flying LTVA-7Ds. That was not entirely inaccurate since the outfit did use these planes for support training. The group received its first production stealth aircraft on September 2, 1982. The 4450th moved to Tonopah in 1983, equipped with a partial squadron of stealth bombers plus a few A-7Ds. The group achieved initial operational capability on October 28, 198, with a total of 14 production aircraft on hand. To avoid having the 4450th's aircraft seen by curious observers, all flying took place at night. During the day, the aircraft were always kept behind closed doors inside special hangars. The stealth bomber turned out to be quite easy to fly. It was concluded that no 2-seat trainer version was required. However, there was a training simulator.

The Air Force considered using the stealth bomber in the invasion of Grenada during Operation "Nickel Grass" in 1983. However, the operation was so swift that the action lasted only a couple of days, and the combat debut of the stealth was put off. In October of 1983, the U.S. government considered using the stealth fighter in a retaliatory attack on Hezbollah terrorist forces based in southern Lebanon in response to the destruction of the Marine barracks in Beirut. In anticipation of action, the 4450th TG at Tonopah was put on alert. 5-or-7 stealth bombers were armed and had their INS systems aligned for attacks on targets in Lebanon.

The plan was for these planes to fly from Tonopah to Myrtle Beach, South Carolina where they would be put insecure hangars. They would then wait for 48 hours for the crews to rest before being given the order to take off for a nonstop flight to Lebanon. However, Defense Secretary Casper Weinberger scrubbed the mission 45 minutes before the aircraft were to take off for South Carolina.

On April 4, 1986 during Operation "El Dorado Canyon", the United States attacked Libya in retaliation for state-sponsored terrorism. During the initial planning for the raid, the use of the still-secret stealth fighter in the operation

was seriously considered. However, once again, the operation was short-lived, and the stealth fighter was not used.

In spite of the extreme security, some bits-and-pieces of the stealth fighter story did manage to leak to the press. In October of 1981, Aviation Week reported that an operational stealth "fighter" was in development. Several people reported catching some fleeting glimpses of a rather odd-looking aircraft flying at night out in the Western desert. More-and-more stuff leaked to the media, so that all through the 1980s it had been sort of an open secret that the USAF was operating a “stealth fighter” which was invisible to conventional radar. However, questions directed to the Pentagon by the Press about the stealth fighter were met either with official denials or by a curt “no comment”. Which only served to whet peoples" curiosity even further.

The official designation of the rumored stealth fighter was assumed by just about everyone to be "F-19", since that number had had not been assigned to any known aircraft. The novelist Tom Clancy placed the stealth bomber (named “F-19 Ghostrider” by him) in a key role in his techno thriller novel Red Storm Rising, published in 1986. The Testors plastic model airplane company marketed a kit which purported to the true configuration of the “stealth” fighter. In the meantime, training continued out in the Nevada desert.

On July 11,1986, Major Ross E. Mulhare flew into a mountain near Bakersfield, California while flying production aircraft number 7 (tail number "792"). Major Mulhare seems to have made no attempt to eject and was killed instantly, his aircraft disintegrating upon impact. A recovery team was immediately dispatched to the crash site and the entire area was cordoned off. Every identifiable piece of the crashed plane was found and removed from the area to prevent them from falling into the “wrong hands”. This is a standard practice for any US military stealth and/or secret program.

The doomed aircraft had reportedly carried a flight data recorder, which is sort of unusual for a USAF fighter. Even though not much was found that was any bigger than a beer can, the flight recorder was supposedly recovered intact. In order to throw scavengers, the media, and the merely curious off the track, the recovery crew took the remains of a crashed F-101A Voodoo that had been at Groom Lake for over 20 years, broke them up, and scattered them throughout the area. The cause of the crash has never been officially revealed. But fatigue and disorientation during night flying has been identified as a probable cause.

On October 14,1987 while flying production aircraft number "30" (tail number 815), Major Michael C. Stewart crashed in the Nellis range just east of Tonopah. He too apparently made no attempt to eject and was killed instantly. Again, the official cause was never revealed, but fatigue and disorientation may have both played a role. There was no Moon that night. And there were no lights out on the Nellis range to help the pilot to distinguish the ground. Reportedly, the mission included certain requirements that were deleted from the final accident report. It is possible that Stewart was going supersonic when he crashed. And he had become disoriented during high-speed maneuvers and had simply flown his plane into the ground. These 2 accidents along with a need to better integrate the still-secret stealth fighter into its regular operations, forced the Air Force to consider flying the aircraft during daytime hours. This would in turn force the Air Force to reveal the existence of the aircraft. This announcement was originally scheduled to take place in early 1988, but internal Pentagon pressure forced a ten-month delay.

On November 10, 1988, the long-rumored existence of the “stealth bomber” was finally officially confirmed by the Pentagon. A poor-quality photograph was released. The stealth bomber was kept secret for over 10 years - the security and deception being so effective that all descriptions which had “leaked” to the media were completely inaccurate.

On the same day, the Air Force confirmed that the official designation of the stealth bomber was F-117A, which surprised just about everyone. The official designation of the stealth fighter had long been assumed by just about everyone to be F-19, since that number had apparently been skipped in the new fighter designation sequence which was introduced in 1962. In addition, it had always been assumed that the designation F-111 had been the last in the old series of fighter designations which been abandoned in 1962 when the Defense Department restarted the whole sequence over again from F-1. This led to a seeming endless round of rumors and speculation about aircraft designation gaps and secret projects which continue to the present day.

If the stealth bomber was not designated F-19, then just what was F-19? If the F-117A was part of the old F-sequence, then what happened to F-112 through F-116? The true answer is not yet known, but the most likely explanation is that the 117 number is NOT in the old F-sequence that ended in 1962 but instead originated from the radio call signs used by the Stealth pilots when they were flying out of Groom Lake and Tonopah - two of the black planes" bases. Those

are the same airfields that secretly operated Soviet-bloc Aircraft such as the MiG-15, MiG-19, MiG-21, and MiG-23 that the US had “acquired” by various means from such sources as Egypt, Israel, Romania, etc. While in flight, these aircraft were distinguished from each other by 3-digit radio call-signs (generally 11x). After awhile, these radio call-signs came to be sort of unofficial designations for these aircraft. And even later, F-prefixes began to be attached to these designations.

The F-112 to F-116 are often speculated to be Soviet aircraft such as Su-22, MiG-19, MiG-21, MiG-23, or MiG-25. There is even a rumor that there exists a F-116A, which is a US-built version of the MiG-25 constructed to see what kind of threat the MiG-25 could be if Russia builds it using Western techniques. There is also thought to be an F-118, which might be a Mig-29 that was purchased before the fall of the USSR.

Since the stealth bomber was operating in the same general area in Nevada, it came to be known by the radio call sign of "117". The number "117" became so closely associated with the stealth bomber that when Lockheed printed up the first Dash One Pilot Manual, it had “F-117A” on the cover. Since the Air Force didn’t want to pay millions of dollars to re-do all the manuals, the aircraft became the "F-117A" officially. It may have even been initially designated "F-19" in the early stages of the project and might well have continued to be known as the F-19 had this mistake not been made. A similar mistake was made when LBJ announced the existence of the “Blackbird”. It was supposed to have been designated RS-71, but President Johnson announced it as “SR-71" and no one had the guts to tell LBJ that he had goofed. The designation stuck.

This still leaves the question of the missing "F-19" unanswered. Perhaps the "F-19" refers to some other “black” project yet unrevealed. Perhaps the "F-19" does not exist at all - the designation having been deliberately or accidentally skipped. Shortly after the official revelation of the F-117A, an Air Force spokesman answered questions about the “missing” F-19 by stating the F-19; designation had been deliberately skipped to prevent confusion with the Soviet MiG-19.

Another possibility that has been mentioned by several people is that the F-19 designation was deliberately skipped in order to let Northrop receive the designation F-20 for its advanced version of the F-5 fighter. Apparently, Northrop thought that the "F-20" designation would make for good advertising

copy for its new fighter. And the Air Force agreed. A similar thing happened during World War II when the designation "P-74" (and perhaps "P-73" as well) were not assigned so that the Fisher Body division of General Motors could get the designation P-75 for its Eagle heavy escort fighter (“The French 75 in World War I The Fisher P-75 in World War II”).

The 4450th Tactical Group was disbanded in October of 1989 and the 37th Tactical Fighter Wing was established in its place. The 37th TFW had 3 squadrons - the 415th, 416th, and 417th. The 415th and 416th squadrons flew production F-117As, whereas the 417th flew the pre-production F-117As. The 417th also operated some LTVA-7Ds for chase and training. But T-38A and AT-38B aircraft eventually replaced them.

In 1994, there has been some thought given to building a “Navalized” version of the stealth fighter to replace the cancelled A-12 project. This would produce a new set of challenges for designers. The aircraft would have to have catapult attachment points and arrester hooks and still be capable of maintaining the integrity of its stealthy exterior. Afterburning engines would presumably have to be fitted to make carrier launchings with heavy payloads feasible, which would require that the complex exhaust system be completely redesigned. If this project is funded, it will be given the designation F-117N. This was never materialized.

The last production F-117A was delivered to the Air Force on July 12h 1990. In 2008, F-117A was officially phased out of US Air Force inventory.

Although the F-117A has been called Frisbee, Nighthawk, and Wobblin Goblin, there is no official name for it. Pilots often nickname the F-117A the “Black Jet”. F-117A number 781 which is now on display at the Wright-Patterson AFB Museum at Dayton, Ohio and one is on public display in front of Skunk Works building, Palmdale (**Figure 7-20**). The one at Wright Patterson base was one of the 5 full-scale development machines. In the interest of security, the RAM covering was replaced by a layer of black paint, and the narrow-slotted exhaust ports were faired over to prevent anyone peering inside to see the details of how the exhaust was constructed. Few others are also on display in the different places. The Other F-117A (parts) is on exhibition at Belgrade Aeronautical Museum (**Figure 7-16**, **Figure 7-17**, **Figure 7-18**, **Figure 7-19**). Part of F-117A are also in Russia and China.

Maintenance issues

F-117A is a fairly complicated airplane from the maintenance perspective. There are a lot of issues that maintenance crews need to deal with which are different with the classic “aluminum” airplanes, often called “aluminum chums” by the stealth pilots. Beside designated maintenance technicians which are common to all other non-stealth airplanes, F-117A squadron has a group of technicians called MARS or known as “Martians” by others. That group is in charge to maintain stealthiness of all F-117A jets in the unit.

Most of the radar-absorbing material (RAM) comes in sections with an adhesive backing similar to masking tape. Each of the sections are joined together by a material the technicians call "butter", a caulking compound that is applied between the old material and the new section of radar absorbing material. It is a grayish and similar to the caulk used to seal the doors and windows. that is where the similarities stops. RAM is applied over the entire exterior of the airplane. Even screw heads on access panels along the fuselage and wings get a special coating of "butter". The composition of "butter" is close guarded secret as well as RAM.

Overseas deployment creates additional strains. After the airplane landed after the combat mission, a group of technicians inspect every square centimeter of the aircraft to make sure there were no cracks, bubbles or pieces of coating missing. Before any other flight, each defect must be corrected. the coating in some areas has to be constantly removed and replaced. First combat missions over Yugoslavia created additional strain for the maintenance crews because before that the aircrafts operated mostly in the desert areas where the dry hair didn't create major damage to the RAM coats.

One of the most enigmatic details of the F-117A is a component called the Radar Locating System (RLS) in the flight manual (**Figure 7-15**) which is also known as a Radar Warning Receiver (RWR). More information about this subject is addressed in Chapter 8, heading Mystery of the Radar Warning Receiver and in particular is related to the speculations did the pilot of the downed F-117A had a warning signal that he is illuminated and tracked by the Low Blow fire control radar.

Just Cause

On December 19, 1989, just 13 months after the Pentagon disclosed the existence of the F-117A, it was used in combat for the first time. This was in Operation “Just Cause” the invasion of Panama intended to dislodge and arrest General Manuel Noriega. At the beginning of the invasion, 6 F-117As flew to Panama from Tonopah. Their mission was to drop 2,000-pound bombs near the Panama Defense Forces (PDF) barracks at Rio Hato. The purpose of these bomb drops was to stun and disorient the PDF troops living there so that the barracks could be stormed, and the troops captured with minimal resistance and casualties.

Its first mission combat mission was during the United States invasion of Panama in 1989. In support of the operation Just Cause, the military intervention to remove Panama president Noriega, at 1400 hours local time on December 19, 1989, eight F-117As launched from Tonopah (two airborne spares returned following completion of the initial air refueling (AR). The decision to employ the F-117A was based upon its bomb-delivery accuracy; Panama did not possess a radar defense network, so the aircraft's stealth features were irrelevant. It was more or less practice "target shooting". The three-thousand-mile round trip from Tonopah to England AFB, Louisiana, required five air refueling and was supported by KC-10s and KC-135s tankers.

Of the six aircraft in the strike package, two were airborne spares, two were tasked with attacking the Rio Hato army base, and the other two were designated to hit Noriega's residences at the Rio Hato beach house and La Escondida mountain resort. In the event, the planned attacks on the president's residences were canceled, when intelligence reports indicated that the intended target would not be present at either location. However, Maj. Greg Feest, flying aircraft 816, and his wingman Maj. Dale Hanner, dropped two 2,000lb GBU-27s in an open field adjacent to the barracks.

The pilots were instructed to drop their bombs no closer than 50 meters from 2 separate PDF barracks buildings. The purpose of the target selection was to stun and confuse, rather than kill, the sleeping soldiers before they had an opportunity to engage US Rangers parachuting in to occupy the Rio Hato airstrip, 90 seconds after the F-117 strike. However, three hours before the

invasion was due to begin, the Panamanian military gained advanced warning of the impending invasion and deployed to the Rio Hato airstrip. The bombing results were not as effective as had been planned, and several Rangers were killed, and more than a dozen wounded in the ensuing firefight before the airfield could be secured. As for president Noriega, having initially taken refuge in a church, he was eventually extradited to Florida. The first blood has been drawn.

It was revealed 3 months later that one of the bombs missed its target by a considerable amount. It seems that there had been some miscommunication in the final stages of the mission planning, and the pilot had been given the wrong coordinates for the target.

The media jumped on this event and concluded that the F-117A had been a failure on its first mission. On April 21st, 1990, stung perhaps by the Press criticism, the Pentagon released more information on the F-117A. More photos of better quality were released, and at Nellis AFB there was a public display of 2 -117As.

Just 13 months after Panama invasion, the new war exploded on the sands of Arabian Peninsula, which will make F-117A reach his full glory.

Desert Storm

At 02:00 hours (Baghdad time) on August 2, 1990, Iraqi forces led by three elite Republican Guard armored divisions invaded Kuwait. Over the next four months countless resolutions condemning Iraq were passed at the United Nations, culminating in Resolution 678, which overwhelmingly approved the use of all necessary means to drive Iraq from Kuwait after January 15, 1991. King Fahd ibn Abd al-Aziz Al Saud of Saudi Arabia invited Western troops into his country on August 6, and within two days a vast buildup of aircraft and troops began, signaling the start of Operation Desert Shield.

On September 5, Gen. Buster Glosson presented the air campaign plan to Gen. Norman Schwarzkopf, who enthusiastically endorsed and approved it Meanwhile, USAF aircraft acted as ferrets, flying to Iraqi border areas to "stimulate" their air defenses and thereby enabling communications intelligence (COMINT) and electronic intelligence (ELINT) assets to map the Iraqis' electronic air order of battle (EAOB).

The Iraqi air defense network was very sophisticated, and its destruction would chronically disable their tight central control system. Over 400 observations posts could send basic heading and altitude data to a command post. This data was supplemented by 73 radar-reporting stations feeding into 17 Intercept Operations Centers (IOCs). Four Sector Operations Centers (SOCs) then controlled the IOCs, and from these three-story, reinforced-concrete centers the defense of enormous areas of Iraq could be planned. Basic targeting information was then supplied to a vast number of missile and AAA batteries.

The suppression of enemy air defenses – or SEAD – was therefore the top priority in order to establish air superiority. Gen Glosson's attack plan had objectives to destroy communication network, radar warning system, disrupt communication and control nodes, force air defense units in autonomous modes, use unmanned aerial vehicles and drones for deception and employ maximum anti radiation missiles.

A defense network command centers would be taken out by the F-117As at the outset, as would key early-warning radars and communication links. The tentacles would then be dealt with by other, non-stealthy assets. If successful, the

plan would have two benefits: without the integrated defense network, SAM batteries would be forced to use their radars longer, making them more vulnerable to attack from anti-radiation missiles; and, cut off from their GCI (ground-controlled interception) controllers, Iraqi fighter pilots would become easy prey for allied air defense assets.

“H” hour was to be 03:00 hours Baghdad time. Consequently, at 00:22 hours on the 17th, the first of three waves of F-117As climbed out of Khamis Mushait AB to deliver the opening salvos of an air campaign that would not just validate the success of the F-117A and stealth technology but would change the shape of air combat forever.

Other than at very close ranges, the F-117A was effectively invisible to these systems. Operations over Iraq in 1991 resulted in no losses for the F-117A, and only minor battle damage produced mostly by shrapnel and fragment damage from larger caliber anti-aircraft artillery barrages. This was not officially acknowledged by US officials. An operation during this campaign which attracted little comment was a deep penetration raid at the start of the campaign, conducted by AH-64 Apache gunships and MH-53 Jolly Greens, to destroy a VHF band P-18 Spoon Rest and a collocated UHF band P-15 Flat Face and P-15M Squat Eye. The reasons for this unusual raid were never disclosed, but a good case can be made that these radars could have alerted Saddam's air defence system to the first wave of F-117As inbound to Baghdad. Those radars can detect and trace stealth aircraft like the F-117, which are designed to operate against radars operating in the C, X and Ku-bands. The Apaches cleared the path for the stealth fighters to proceed to their targets deep inside Iraq undetected.

During the Gulf War in 1991, the F-117A flew approximately 1,300 sorties and scored direct hits on 1,600 high-value targets in Iraq over 6,905 flight hours. Psychological effect on Iraqis' troops was enormous. Leaflet drops on Iraqi forces displayed the F-117A destroying ground targets and warned "Escape now and save yourselves". Initial claims of its effectiveness were later found to be overstated. For instance it was claimed that the F-117A made up 2.5% of Coalition tactical aircraft in Iraq and they attacked more than 40% of the strategic targets; this ignored the fact that only 229 Coalition aircraft could drop and designate laser-guided bombs of which 36 F-117A represented 15.7%, and only the USAF had the I-2000 bombs intended for hardened targets, so the F-117A represented 32% of all coalition aircraft that could deliver such bombs. Initial reports of F-117As hitting 80% of their targets were later scaled

back to "41–60%". On the first night, they failed to hit 40% of their assigned air-defense targets, including the Air Defense Operations Center in Baghdad, and 8 such targets remained functional out of 10 that could be assessed. In their Desert Storm white paper, the USAF claimed that "the F-117A was the only airplane that the planners dared risk over downtown Baghdad" and that this area was particularly well defended. In fact, most of the air defenses were on the outskirts of the city and many other aircraft hit targets in the downtown area, with minimal casualties when they attacked at night like the F-117A. This meant they avoided the optically aimed AAA and infra-red SAMs which were the biggest threat to Coalition aircraft.

The aircraft was operated in secret from Tonopah for almost a decade, but after the Gulf War the aircraft moved to Holloman in 1992 - however its integration with the USAF's non-stealth "iron jets" occurred slowly. As one senior F-117A pilot later said: Because of ongoing secrecy others continued to see the aircraft as "none of their business, a stand-alone system". The F-117A and the men and women of the 49th Fighter Wing were deployed to Southwest Asia on multiple occasions. On their first deployment, with the aid of aerial refueling, pilots flew non-stop from Holloman to Kuwait, a flight of approximately 18.5 hours - a record for single-seat fighters that stands today.

After the Gulf War, general public, with the help of propaganda partially fueled by the pentagon and US media, believed that the stealth aircraft is invisible. For the military expert's stealth aircraft were not invincible nor are they invisible to radar and infrared. Military and national security professionals have never had such illusions, but during the 1990s, many grew overconfident in the capabilities offered by low observable aircraft. But stealth is mere delayed detection and tracking - the idea is one releases their weapons before the enemy is aware of you. Stealth is not a magical cloak of invisibility. the next chapter will prove this.

Figure 7-1 (left top) Clarence "Kelly" Johnson
(Source: Wikipedia)

Figure 7-2 (right top) Ben Rich (Source: Lockheed Martin, Wikipedia)

Figure 7-3 (left): Denys Overholser
(Source: Lockheed Martin via statesmanjournal.com)

Figure 7-4: Hopeless Diamond
(Source: Pinterest)

Figure 7-5: Have Blue (Source: Pinterest)

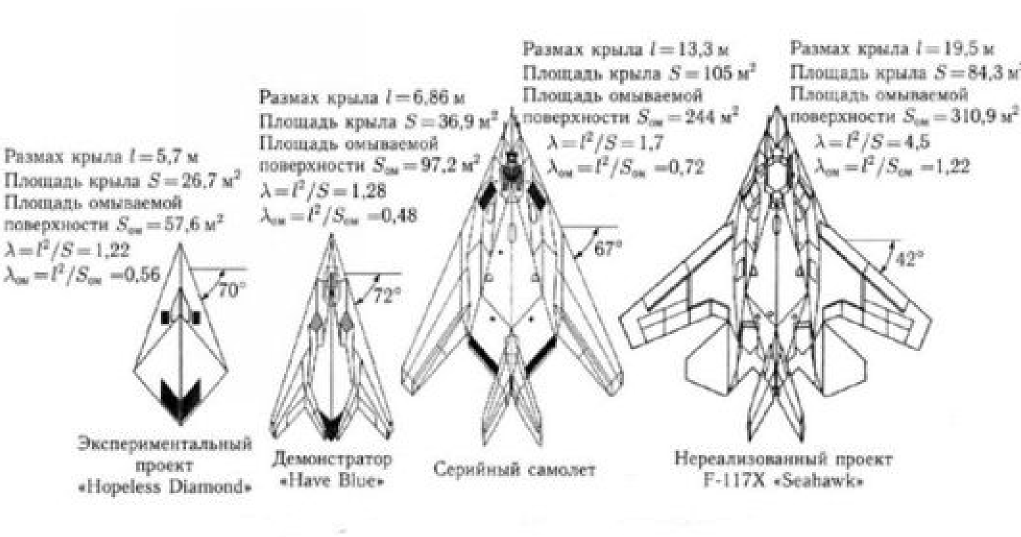


Figure 7-6: F-117 Evolution from Russian source
(Source: Harakteristiki radiolokacionih Zametnosti Letalnih Aparatov)

Figure 7-7: Serial F-117A (Source: USAF)

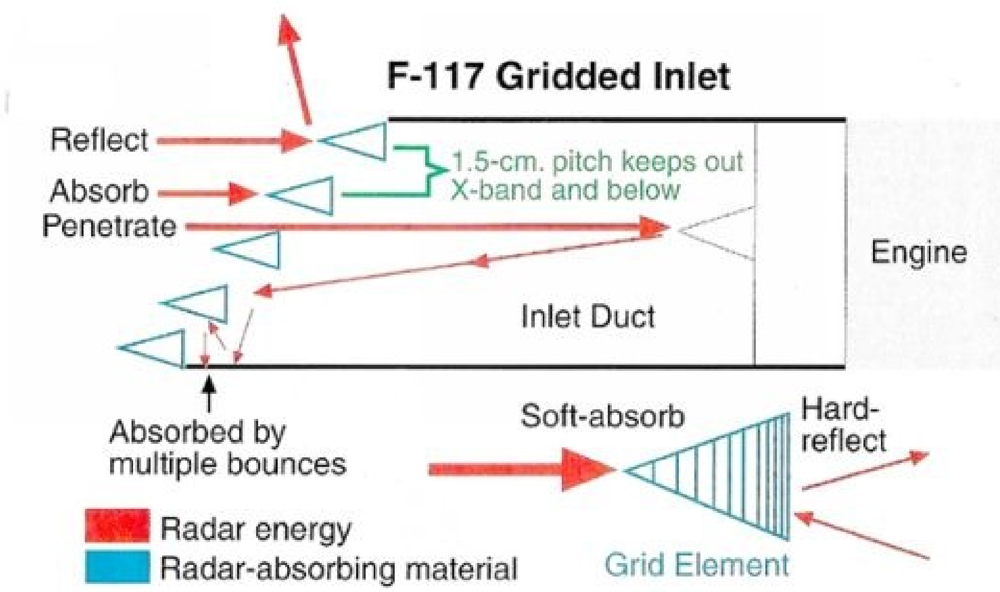


Figure 7-8: F-117 Gridded inlet (Source: Pinterest)

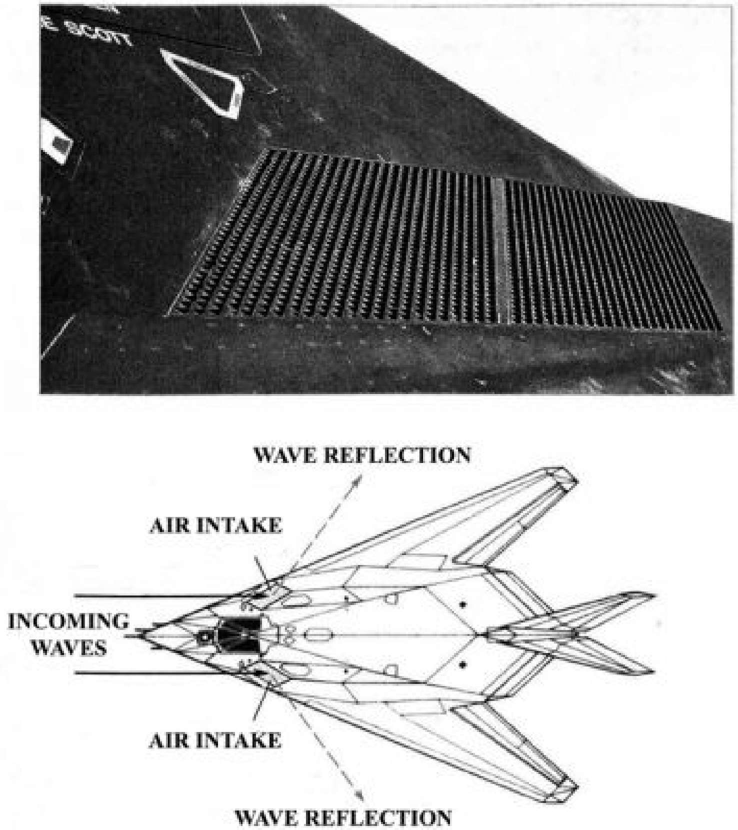
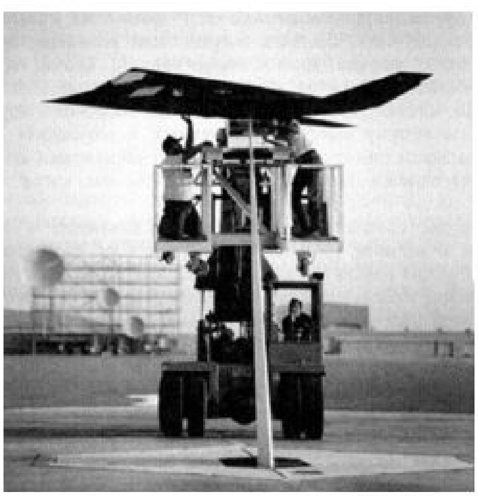


Figure 7-9: F-117 Engine inlet wave reflection
(Source: Harakteristiki radiolokacionih Zametnosti Letalnih Aparatov)



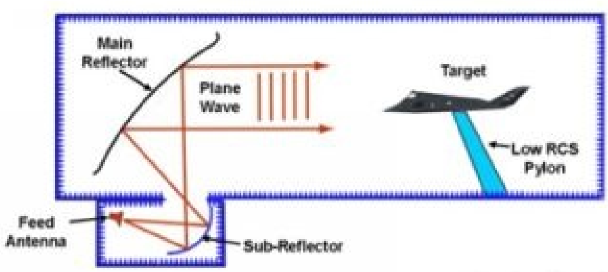


Figure 7-10: F-117 RCS measurements
(Source: Harakteristiki radiolokacionih Zametnosti Letalnih Aparatov)

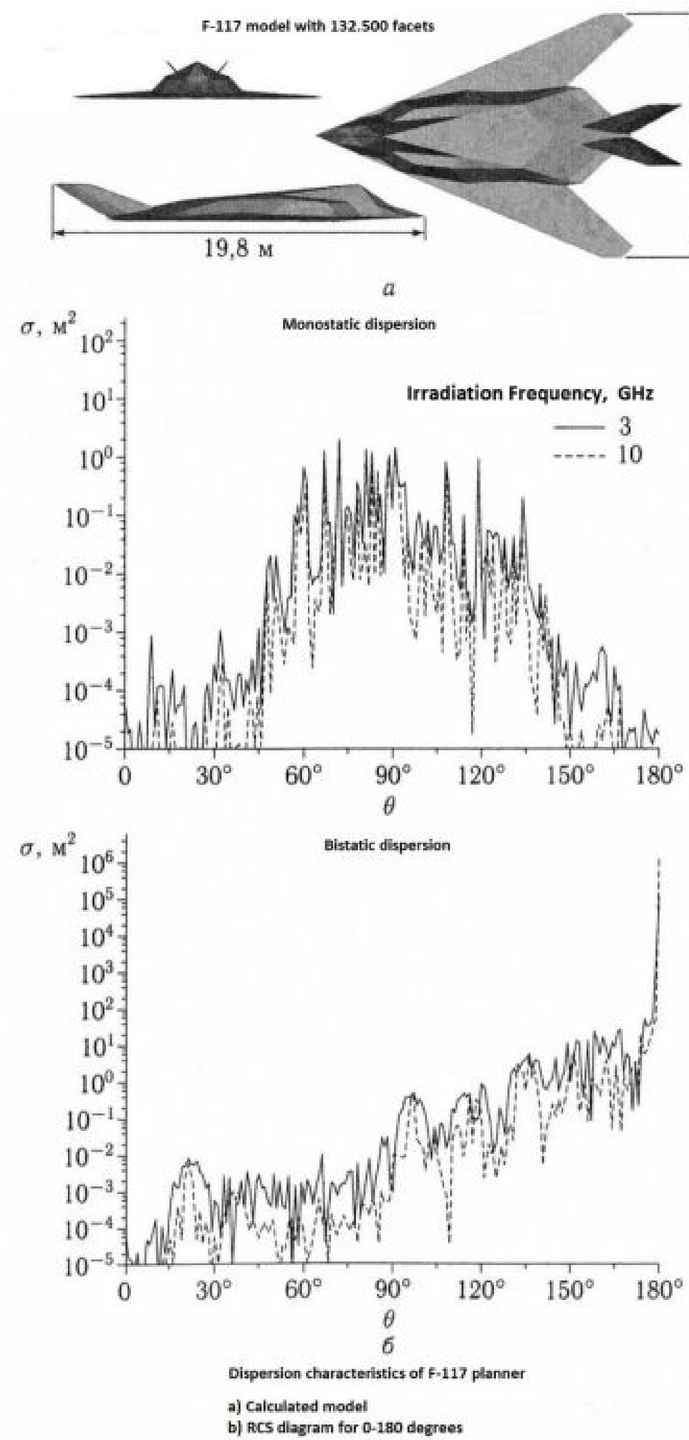
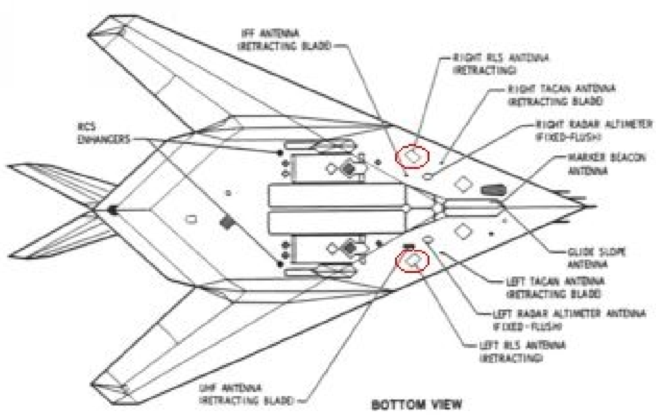


Figure 7-11: F-117 RCS for monostatic and bistatic dispersion
(Source: Harakteristiki radiolokacionih Zametnosti Letalnih Aparatov)

Figure 7-12: F-117 "platypus" exhaust
(Source: USAF)

Figure 7-13: F-117 cockpit canopy
(Source: USAF)



RADAR LOCATOR SYSTEM

The Radar Locator System (RLS) is not supported and is disabled. The RLS control panel (see Figure 4-19) is retained to allow the antenna assemblies to be retracted for flight or deployed for maintenance access.

RLS CONTROL PANEL

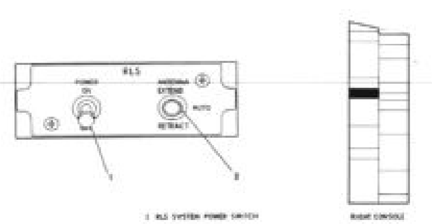


Figure 7-15: F-117A Radar Locator System (see Chapter 8 for details)
(Source: USAF Utility Flight Manual TO-1F-117A-1)

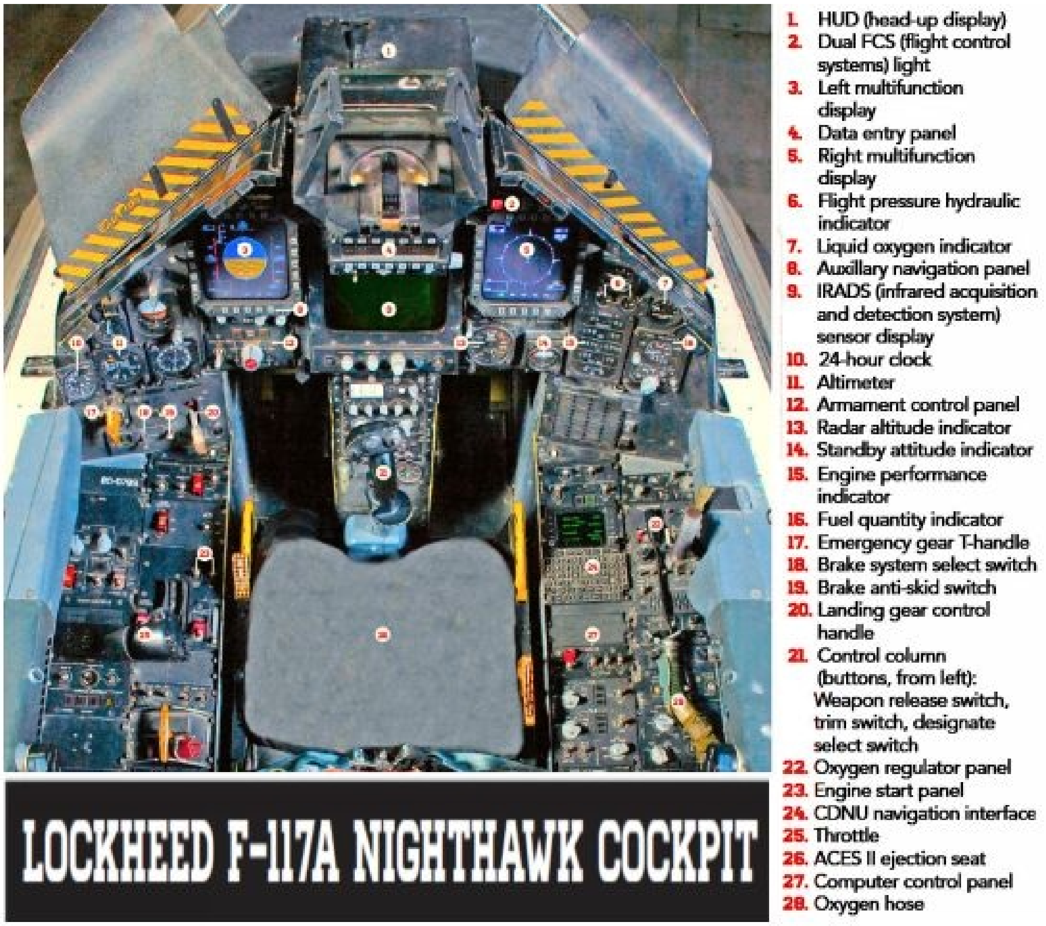


Figure 7-14: F-117 cockpit. Note there is no radar warning receiver indicator (Source: Pinterest)

Figure 7-16: F-117A wing on public display at Belgrade Aeronautical Museum
(Source: Authors)

Figure 7-18: F-117A wing in Belgrade Aeronautical Museum depot
(Source: Authors)

Figure 7-19: F-117A cockpit canopy on public display at Belgrade Aeronautical Museum (Source: Wikipedia)

Figure 7-20: F-117A on public display in front of Skunk Works Palmdale building, CA (Source: Wikipedia)

Chapter Eight

Prelude to War

Balkan peninsula, through the history, was known as a "powder keg" which needs a very small spark to explode. Those sparks were very often and the explosions occasionally ignited wars far beyond the peninsula geographic border.

The Serbian-Kosovo Albanian conflict has its roots in centuries prior to the 1999 conflict. Territory of Kosovo and Metohija has been considered of the birth place of Serbian state during the medieval times. Albanian tribes came to the Serbian territory on approval from the Serbian kings as a shepherds and populated mountainous regions. During the decline and disintegration of the medieval Serbian kingdom, Albanians converted into Islam and integrated themselves into the Ottoman Turks Empire. Since then the two peoples have had problems with each other. Kosovo was liberated form the Ottoman rule in the first Balkan war but at that time Serbian population was greatly expelled from the territory as multiplications of the Albanian tribes thrives. Serbian government has never been accepted and occasional riots, sometimes paid by the foreign powers such as Austro – Hungary and Italy, arise. During the World War II majority of Albanian population sided with the fascist Italy and even formed SS division Skenderbeg. What was left of the Serbian population in many Kosovo areas has been expelled or killed in the series of pogroms. After the war, the anti-Serbian communist regime banned return of the Serbian refugees to their homes. However, some Serbian politicians raised against the communist regime policies.

The 1950s and 1960s were a period marked by policies in Kosovo under Aleksandar Ranković, a Serbian communist who later fell out and was dismissed by Yugoslav president, communist dictator Tito. During this time nationalism for Kosovar Albanians became a conduit to alleviate the conditions of the time. In 1968 Yugoslav Serb officials warned about rising Albanian nationalism and by November unrest and demonstrations by thousands of Albanians followed calling for Kosovo to attain republic status, an independent Albanian language university and some for unification with Albania. Tito rewrote the Yugoslav constitution (1974) and tried to address Albanian complaints by awarding the province of Kosovo autonomy and powers such as a veto in the federal decision making process similar to that of the republics.

Kosovo functioned as a de facto republic because Kosovar Albanians attained the ability to pursue near independent foreign relations, trade and cultural links with Albania, an independent Albanian language university and Albanology institute, an Academy of Sciences and Writers association with the ability to fly the Albanian flag.

Military precursors to the terrorist organization "Kosovo Liberation Army" (KLA) began in the late 1980s with armed resistance to Serb police trying to take Albanian activists in custody. Prior to the KLA, its members had been part of organizations such as the National Kosovo Movement and Popular Movement for Kosovo Liberation. The founders of the later KLA were involved in the 1981 protests in Kosovo. Many ethnic Albanian dissidents were arrested or moved to European countries, where they continued subversive activities. Repression of Albanian nationalism and Albanian nationalists by authorities in Belgrade strengthened the independence movement and focused international attention toward the plight of Kosovar Albanians.

From 1991 to 1992, Albanian nationalist Adem Jashari and about 100 other ethnic Albanians wishing to fight for the independence of Kosovo underwent military training in the municipality of Labinot-Mal in Albania. Afterwards, Jashari and other ethnic Albanians committed several acts of sabotage aimed at the Serbian administrative apparatus in Kosovo. Attempting to capture or kill him, Serbian police surrounded Jashari and his older brother, Hamëz, at their home in Prekaz on 30 December 1991. In the ensuing siege, large numbers of Kosovo Albanians flocked to Prekaz, forcing the Serbs to withdraw from the village. While in Albania, Jashari was arrested in 1993 by the government of Sali Berisha and sent to jail in Tirana before being released alongside other Kosovo Albanian militants at the demand of the Albanian Army. Jashari launched several attacks over the next few years, targeting the Yugoslav Army (VJ) and Serbian police in Kosovo. In the spring of 1993, "Homeland Calls" meetings were held in Arau, Switzerland, organized by Xhavit Halili, Azem Syla, Jashar Salihu and others. KLA strategist Xhavit Halili said that in 1993, the KLA considered and then rejected the IRA, PLO and ETA models'. Some journalists claim that a May 1993 attack in Glogovac that left five Serbian policemen dead and two wounded was the first one carried out by the KLA.

By early 1990s there were attacks on police forces and secret-service officials. A Serbian policeman was killed in 1995, allegedly by the KLA. Since

1995, the KLA sought to destabilize the region, hoping the United States and NATO intervene. Serbian patrols were ambushed and policemen killed. It was only in the next year that the organization of KLA took responsibility for attacks.

The KLA, originally composed out of a few hundred Bosnian War veterans, Muslims Albanians, attacked several police stations and wounded many police officers in 1996–97.

In 1996 the British weekly magazine “The European” carried an article by a French expert stating that "German civil and military intelligence services have been involved in training and equipping the rebels with the aim of cementing German influence in the Balkan area. (...) The birth of the KLA in 1996 coincided with the appointment of Hansjoerg Geiger as the new head of the BND (German secret Service). (...) The BND men were in charge of selecting recruits for the KLA command structure from the 500,000 Kosovars in Albania." Former senior adviser to the German parliament Matthias Küntzel tried to prove later on that German secret diplomacy had been instrumental in helping the KLA since its creation.

KLA representatives met with American, British, and Swiss intelligence agencies in 1996, and possibly "several years earlier" and according to “The Sunday Times”, American intelligence agents have admitted they helped to train the Kosovo Liberation Army before NATO's bombing of Yugoslavia. Intelligence agents denied, however, that they were involved in arming the KLA.

In February 1996 the KLA undertook a series of attacks against police stations and Yugoslav government employees, saying that the Yugoslav authorities had killed Albanian civilians as part of an ethnic cleansing campaign. Serbian authorities denounced the KLA as a terrorist organization and increased the number of security forces in the region. This had the counter-productive effect of boosting the credibility of the embryonic KLA among the Kosovo Albanian population. On April 26, 1996, four attacks on Serbian security personnel were carried out almost simultaneously in several parts of Kosovo.

In January 1997, Serbian security forces assassinated KLA commander Zahir Pajaziti and two other leaders in a highway attack between Pristina and Mitrovica, and arrested more than 100 Albanian militants. Jashari was convicted of terrorism in absentia by a Yugoslav court on July 11, 1997. Human Rights Watch subsequently described the trial, in which fourteen other Kosovo

Albanians were also convicted, as "failing to conform to international standards."

The Albanian interior conflict of 1997 enabled the KLA to acquire large amounts of weapons looted from Albanian armories. A 1997 intelligence report stated that the KLA received drug trafficking proceeds, used to purchase arms. The KLA received large funds from Albanian diaspora organizations. There is a highly possibility that among donators to the KLA were people involved in illegal activities such as drug trafficking, however insufficient evidence exists that the KLA itself was involved in such activities.

Some people from non-Albanian communities such as the Serbs and Romani fled Kosovo fearing revenge attacks by armed people and returning refugees while others were pressured by the KLA and armed gangs to leave. According to the report of the U.S. Committee for Refugees the KLA attacks "aimed at trying to 'cleanse' Kosovo of its ethnic Serb population". The Yugoslav Red Cross had estimated a total of 30,000 refugees and internally displaced persons (IDPs) from Kosovo, most of who were Serb. The UNHCR estimated the figure of at least 55,000 refugees who had fled to Montenegro and Central Serbia, most of whom were Kosovo Serbs: "Over 90 mixed villages in Kosovo have now been emptied of Serb inhabitants and other Serbs continue leaving, either to be displaced in other parts of Kosovo or fleeing into central Serbia."

James Bissett, Canadian Ambassador to Yugoslavia, Bulgaria and Albania, wrote in 2001 that media reports indicate that:

> *"As early as 1998, the Central Intelligence Agency assisted by the British Special Air Service were arming and training Kosovo Liberation Army members in Albania to foment armed rebellion in Kosovo" with the hope that "NATO could intervene (...)".*

Pursuing Adem Jashari for the murder of a Serbian policeman, Serbian forces again attempted to assault the Jashari compound in Prekaz on 22 January 1998. With Jashari not present, thousands of Kosovo Albanians descended on Prekaz and again succeeded in pushing the Serbian forces out of the village and its surroundings. The next month, a small unit of the KLA was ambushed by Serbian policemen. Four Serbs were killed and two were injured in the ensuing clashes. At dawn on 5 March 1998, the KLA launched an attack against a police patrol in Prekaz, which was then answered by a police operation on the Jashari

compound which left 58 Albanians dead, including Jashari. Four days after this, a NATO meeting was convoked, during which Madeleine Albright pushed for an anti-Serbian response. NATO now threatened Serbia with military response. The Kosovo War ensued, with subsequent NATO intervention. A NATO - facilitated ceasefire was signed on 15 October, but both sides broke it two months later and fighting resumed.

The infamous spark which lighted the powder keg happened when the alleged “killing” of 45 Kosovar Albanians in the Račak massacre was reported in January 1999 by the western media. It was nothing that provocation set up by NATO secret services in cooperation with the KLA. It was proven after the war by independent bodies that like the bombing of the marketplace in Sarajevo (Markale incident) which was trigger for economic blockade of Yugoslavia; it was staged massacre where bodies of deceased people were riddle by bullets than shown to the media. Just a few of the bodies were actually terrorists that were killed by the security forces. After the CIA agent and OSCE mission head William Walker filled the report, NATO decided that the conflict could only be settled by introducing a military peacekeeping force to forcibly restrain the two sides. After the Rambouillet Accords broke down on March 23 with Yugoslav rejection of an external peacekeeping force, NATO prepared to install the “peacekeepers by force” – very pathetic expression for the nothing else than brutal aggression on the sovereign country.

The “dice has been casted” and this “recipe” will be repeated many more times in the different conflict ahead.

Order of battle

Yugoslavian Air defense

The Serbian air defenses in the “Operation Allied Force”, as the aggression was called by NATO, represented a typical pattern of Soviet air defenses from the 1960-70 period. They are representative of the effects of stagnation in modern surface-to-air missile system proliferation through much of the world that had been dependent on Soviet supplies. As a result, they have implications beyond the Kosovo campaign.

Serbia’s strategic air defense was handled by a declining number of vintage Almaz S-75 (SA-2) and a small number of partly modernized Almaz S-125 Pechora (SA-3). Prior to the Yugoslav civil war, the air-defense command had six batteries of S-75s, totaling about 40 single-rail launchers, of which only three batteries were still operational in 1999. There were also 12 combat batteries of S-125s with 60 x 4-rail launchers - of which about 50 launchers were still operational in 1999. SA-3 systems were grouped in one missile brigade (250th missile brigade) and one independent missile regiment (450th missile regiment).

250th brigade had 8 battalions (1st. Btajnica; 2nd Pancevo; 3rd Jakovo, 4th Zuce; 5th Jakovo, 6th Smederevo; 7th Mladenovac and 8th Obrenovac). Beside combat battalions, 250th brigade also had 2 missile technical battalions which main purpose is missile warehousing, maintenance, preparation and supplies to the combat battalions (1st missile technical battalion in Sremcica and 2nd missile technical battalion in Zuce). Missile defence technical school and training center also had training equipment including one missile guidance station, one engagement and fire control radar and 4 launchers. There were total of 11 missile guiding station available to the 250th brigade which task was defense of the capital city area. 450th regiment with 4 battalions and one technical battalion covered the south west parts of Serbia and industrial city of Kraljevo. In total, there were 15 missile guiding stations available for all SA-3 systems.

Air defense of the field army was handled by five independent regiments of 2K12 Kub (export version Kvadrat, SA-6) mobile radar-directed SAMs, with one of the regiments (311th Independent regiment) based with the Serbian forces in or near the province of Kosovo and Metohija area and two regiments (230th

from Nis and 310th from Kragujevac) based not too far from the province. The 60th regiment was based in Podgorica (Montenegro) and 240th regiment had a base in Novi Sad. Each regiment had 4 batteries. The weakest point on SAM-6 system is 1S91 (Straight Flush) radar vehicle which is needed to provide guidance for every four missile-launch vehicles. This cumbersome arrangement restricted the flexibility of the Kvadrat batteries.

Air defense at divisional level ("Trupna PVO" as per Serbian terminology) included Strela-1 (SA-9) and Strela-10 (SA-13) IR-guided, low altitude, vehicle-mounted SAMs. The more common of these was the older 9K31 Strela-1 (SA-9), with some 113 launcher vehicles delivered to Yugoslavia in the 1970s. The associated missile was manufactured in Yugoslavia under license before the war. The Strela-1 system consists of four missile launchers, mounted on a wheeled BRDM-2 light armored vehicle, and has an effective ceiling of 3,500 m. It employs an older uncooled lead-sulphide seeker with no IR counter-countermeasures capabilities. Yugoslavia received a total of only 17 of the more modern 9K35M Strela-10 (SA-13) in the 1980s. This is an evolutionary descendent of the Strela-1, but mounted on a tracked MT-LB chassis. The Strela-10 has IR counter-countermeasures with later versions of the missile having a two-channel seeker. Besides these standard systems, Serbian air-force units attempted to create improvised air-defense missiles for their bases using IR guided air-to-air missiles. The normal aircraft rail-launchers for R-60 (AA-8 Aphid) and R-73 (AA-11 Archer) were lashed on to ground mountings codenamed "Pracka" (Slingshot).

Small unit air defense was handled by anti-aircraft guns and a significant number of old Strela-2M (SA-7) and new Igla (SA-16/-18) man-portable SAMs. The Strela-2M was produced in Yugoslavia under the name Strela-2M2J Sava and was available in large numbers. Serbia managed to purchase about 75 of the new 9K310 Igla-1 (SA-16) man-portable IR-guided SAM from Kazakhstan and other sources in the mid-1990s. In total, there were about 850 man-portable IR-guided SAMs in the Serbian armed forces in 1999.

NATO took the threat posed by IR-guided SAMs the most seriously, as these had been the primary source of casualties in Operation Desert Storm. There was some confidence that the radar-directed missiles could be dealt with using traditional means of suppression of enemy air defenses (SEAD) and electronic countermeasures (ECM). Unlike radar-guided SAMs, IR-guided SAMs present a serious suppression problem since the launchers rely entirely on passive sensors

and are generally smaller, more mobile and easier to conceal. The older-generation IR-guided SAMs, such as the Strela-2M (SA-7) and Strela-1 (SA-9), use seekers that are more susceptible to conventional ECM, such as flares and “hot brick” IRCM. The newer IR-guided systems, such as the man-portable Igla (SA-16/-18) and vehicle-mounted Strela-10 (SA-13), have more robust counter-countermeasures. Rather than risk aircrews to these systems, NATO planners restricted most air operations above 3000 m (10,000 ft), where these small SAMs have very low probabilities of kill due to kinetic and sensor limits. Furthermore, the presence of these SAMs raised concerns about operating attack helicopters such as the AH-64 Apache deep behind Serbian lines and was a significant factor in US reluctance to deploy the Apaches in combat.

The altitude limits succeeded in minimizing casualties to IR-guided SAMs. A single aircraft was hit by a shoulder-fired SAM, but it failed to fuse and bounced off the aircraft. Several other aircraft were damaged, possibly by this type of weapon. The mere presence of these weapons, however, inhibited air operations to a significant extent. Due to weather conditions, it forced NATO to abandon air missions when cloud cover precluded operations below the altitude limit, and none of the air forces other than the US had munitions such as the Joint Direct Attack Munition (JDAM) that could be used in all-weather conditions. Secondly, it contributed to collateral damage against civilian targets. Although NATO aircraft did have electro-optical sensors for surveying targets before the strike, when used from medium altitudes, the resolution of the image in the cockpit is often mediocre. Civilian tractors and buses can be mistaken for military vehicles (for further details see section in Chapter nine Deceptions).

Yugoslav side paid a close attention to the experience of both coalition and Iraqi sides during the operation Desert Storm. In the command and information department of the air defence forces numerous analyses were performed about the capabilities and tactics of allied strike forces. One of the analyses was about F-117A capabilities. The first conclusion was that the performance of the airplane such as altitude and speed are within the missile system envelopes for both SA-3 and SA-6. What was the issue is how far it can be detected on the surveillance radar and were the capabilities of the existing engagement and fire control radars enough to perform the target acquisition, tracking and engagement. What was not known was the radar cross section. Yugoslav side got the help from an unsuspected source – US Air Force. In one of the publications there was an article about the achieved level of stealth accompanied with appropriate graphics. Yugoslav side conducted numerous calculations comparing

the available information about the airplane and capabilities of the radars. Conclusion was that the available radars in the air defence are able to track and provide fire control solutions and guidance to engage the stealth aircraft. One of the conditions was that all combat procedures must be performed very precisely and accurate.

During the meeting which was held on September 10, 1998, in the Air Defence Command center, it was in detail presented to the Air Force and Defence commander. Shortly after, the students at year 4 of the sir defence academy started with trainings how to calculate range and altitude of stealth aircraft detection for all surveillance radars in air defense. With the very limited capabilities of available equipment, the Yugoslav side has done everything that what was possible to get ready.

USAF and NATO order of battle

For US Forces Order of Battle notable is the high proportion of F-16CJ defence suppression aircraft, around 40% of the total fast jet strike component. Even accounting for provision of escort to aircraft flown by other NATO nations and US heavy bombers, this is a very high proportion of the strike force committed to protection against a collection of mostly obsolescent Soviet era SA systems (**Figure 8-1**, **Figure 8-2**).

Against FRY was also engaged aircraft carrier USS Theodore Roosevelt battle group and amphibious group with support vessels.

Attack

Armed forces of Yugoslavia were able to defend the country against combine attack of two neighborhood counties, but to fight against the most powerful military organization in the world the chances for any success were zero. Statistically, the power was 600:1.

The first indication of the imminent attack was when during the night of March 23 as all international air traffic, which is very dens over Yugoslavia, was re-routed over the surrounding countries. The sky was cleared. Long range surveillance radar couldn't pick up any single airplane over the Yugoslav air space but far over the airspace of Hungary, Romania and Bulgaria. It was simple...the air-space need to be cleared of any civilian flights before the operation start-up. The NATO air attacks started on March 24, 1999.

What NATO tried is to deliver a knock-out punch on the very first night pretty much like the attack on Iraq. In the modern war, there is no chivalry - attacker is using everything on his disposal to achieve the goal: cripple or destroy the enemy without own casualties. Salvoes of cruise missiles launched from NATO airplanes (B-52s), US and UK submarines and warships in Mediterranean area and Adriatic Sea and laser guided bombs hit the positions of radars, missile batteries, command centers, military airports, warehouses... The Tomahawk missiles were timed out to hit command and control centers (C2). Air launched missiles from 2nd Bomb Wing from Louisiana hit the similar targets. Also, a pair of B-2s from Whitman Missouri 509th Bomb Wing base made more than 32 hours round trip flight to strike air defense, arms factories, airfields and weapon storage areas. Bombers were escorted by F-15C fighters, EA-6B electronic warfare aircrafts, KC-135 aerial tankers and NATO E-3 Sentry airborne command and control airplanes.

The very first bombing of the 8th "Black Sheep" squadron was performed by the squadron commander, Lt. Col. Gary Woltering and the target was "radar installation near Belgrade". It is worth to mention that NATO goal at the first night to make Yugoslav defence blind. Lt. Col Zelko also took part in the first attack (**Figure 8-3**, **Figure 8-4**, **Figure 8-8**).

Figure 8-4:F-117A taking off from Aviano on March 24.. (Source: USAF)

Yugoslavs had enough information through the intelligence reports such as NATO build up around the borders, intensifying terrorist attacks in Kosovo by Kosovar separatists, re-routing of the air traffic over surrounding countries and the most logical step for the high command was to order the full battle readiness of the armed forces. In days before the aggression, the air force most modern MiG-29 airplanes were relocated in pairs on the different airports. Those few flight worth airplanes were simply not match for NATO. Pilots were basically sacrificed in the opening hours of the war.

Air-defence units were just started deployment but by no means they were actually ready for combat. What plagued Yugoslav air defence and with them the whole military was the political negligence, no investment in the new weapons systems, lack of training, scarce funding, unhappy junior officers, some incompetent high-ranking officers which advance in the ranks and command post can be achieved only through the political connections with the "elite". With some exceptions, majority of the generals on key positions were simply not up to the tasks such as fighting with the whole NATO pact, but they simply couldn't say "no" to the president because that will automatically mean dismiss from the position and loss of privileges.

Air defence of Federal Republic of Yugoslavia was presented to the population as formidable. That was also picked by western press and can be seen in some documentaries. It was all but formidable. As seen in the section "order of battle" it was just obsolete with the missile systems which were generations older than the modern air forces which were to face soon. Equipment was old, prone to often breaks. There were no funds to buy the new systems or even spare parts. Routine maintenance was simply to try to make something workable, often re-using parts from the other systems which were broken.

To have combat motivated and effective unit, investment in people and technique is necessary. Yugoslav air defense didn't have that at all. People even didn't have the regular paycheques. If any officer in western armies did not get his paycheque for, in example, three months the question what will be his motivation to do anything. Beside all hardship, the core of the units tended to try to do their job.

NATO was very well aware of the capabilities of Yugoslav air defence. It was just fraction strength of Iraqis air defence which were ultimately defeated

and almost destroyed in the first few weeks of fighting. All peace time location of combat positions, radars, munition warehouses, command centers were very well known and as by the book they were first to be attacked. The question for the air defence command was how to survive the first blow. Since the air space over Yugoslavia was cleared, the command had almost 24 hours to dislocate units to the alternative positions. The units waited marching orders for deployment.

3rd battalion

The 3rd battalion was one of eight battalions which were under the command of the 250th missile brigade. Organizationally, the battalion consists of command, command and control platoon, technical battery, missile launcher battery and support platoons. Battalion command consists of commander, Lt. Col. Dani Zoltan; deputy commander and executive officer (XO) Lt. Col Djordje Anicic, commander’s aid for logistics Maj. Bosko Dotlic; commanders’ aid for techniques and equipment, Maj. Boris Stoimenov, to mention few. In total, the battalion was around 200 men strong. The unit had mixed reserve and regular personnel.

Command and control platoon main role were to provide uninterrupted control over the other units and link with the brigade command. Technical battery responsibility is to provide technical support to the fire control center, radars, and launchers and power supply for all equipment. Missile battery includes 4 launchers with 4 missiles each, 16 in total. Responsibility of missile battery is to provide warehousing, transport, preparation for combat and installation on the launchers. Battery consist of two platoons; each platoon is responsible for 2 launchers. 3rd battalions also have automotive section with the trucks and support vehicles (**Figure 8-5**).

In the months prior to the outbreak of hostilities and NATO attack, 3rd battalion was not in the “good shape”. According some of the parameters, the 3rd battalion was the lowest ranking battalion within 250th brigade, as per August 1998 assessment. The biggest problem was in the equipment readiness. There were malfunctions for both missile channels and target channel. The battalion was simply not combat worthy. Much needed command structure changes were initiated, and battalion got the new "fresh blood" infusion. The existing commander, Lt. Col. Dani remained at the position and the new senior officers arrived. The new command structure initiated intensive training activities, which included extensive simulator training, combat crew coordination, procedures for different scenarios etc. Slowly but steady, the combat crews were brought into the acceptable “war readiness” by February 1999. A lot of burden of this peace time transformation fell onto the XO who was the only senior officer trained and experienced on SA-3 system. Beside the regular component, the reserve was also trained. The key in successful training

was personnel motivation and readiness of the available equipment.

Not all senior officers in the battalion were actually trained on SA-2 system. Battalion commander, Lt. Col. Dani, Maj. Stoimenov and Maj. Dotlic were all trained on SA-2. The only senior officer who spent his entire career on SA-3 system was Lt. Col. Anicic. In other words, he knows SA-3 system like a “palm of his hand”. Only junior officer with SA-3 training was 2Lt Crnobrnja who was battalion security officer during the war. It is important to say that the other officers were also knowledgeable of the system operations, but as not as much familiar as Lt. Col. Anicic. The battalion relied on noncommissioned officers for operation and maintenance. Brigade command had SA-3 trained officers but they were not part of the battalion.

The 3rd battalion was in the state of readiness on March 24 until 11:00 when the order has been issued to start the transition from the primary combat position (peace time positions) to the alternative one (reserve fire position Simanovci). Marching order was to deploy one vehicle at time and at the same time to camouflage the primary position with decoys. Forward observers were deployed to the visual observation points. Deployment dragged almost all afternoon. At 19:00 the last truck with the battalion commander left the primary position, towing the last launcher ramp (**Figure 8-6**).

Base camp in the vicinity of Simanovci was at the local community farm where the majority of the unit was based including the transportation section and maintenance. That location before the war was used as a temporary workers place for the seasonal workers. The firing position was actually reserve SA-2 position. It was built as per the older system requirements which are not very well suited for SA-3 system. Prepared firing positions have all power and communication cables and lines pre-installed and the unit need to to basically “plug” the equipment. This prepared system reduces the time necessary to transform the unit from the marching to the combat readiness. In the years before the war there were some intention to fully modify the location to suit SA-3, including the concrete bunker but that was never finalized. With certainty it can be said here that this position was very well known to NATO mission planners. SA-2 system combat position is very distinctive in the foreground on the very flat terrain. There was simply no way to hide it anyway, but also the factor of surprise played the role: logically, why should anybody get to the predetermined and marked up firing positions when the enemy for sure knows for that? If the enemy knows for that position, then they may assume that it will

not be used because it is known and can be easily destroyed. Because of that reason the unit shall be deployed on that position - illogical deceiving option but it may work, at least battalion HQ hoped.

At 19:30 the combat readiness alarm has been issued by the command of the 250th missile brigade, which 3rd battalion belongs. The primary position was in the meantime evacuated with just a few soldiers left there. 20:06 was exact time when the first missile hit the primary position. The first detonation was followed with second one at 20:15 than the third one at 20:20. The primary combat position has been obliterated. In the meantime, all vehicles and ramps have been relocated to the secondary position (**Figure 8-7**).

The deployment has been performed under the vehicle's lights, which was in contrary of the procedure in the time of war. After the intervention of the battalion deputy commander, the lights were turned off and the equipment was deployed in dark. The light portable shoulder launched surface-to-air missile Strela-2M (SA-7) has been deployed in the surrounding area. In the meantime, the observation radars picked the cruise missiles and the concern of the deputy commander was that the position was probably detected by reconnaissance airplanes and the air raid was imminent. The personnel have been ordered to go to the shelters. The major concern was that the enemy knows for the reserve location. After the initial confusion, the battalion has been brought to the full combat readiness at 04:00 next morning. That was almost 6 hours after the initial attack and by all means far beyond the permitted deployment time. It was obvious that the initial confusion took a toll.

The biggest concern was for the people left at the primary position. Fortunately, laser bombs didn't cause any casualties. The position, including decoys has been obliterated, warehouse with 80 missiles completely destroyed. People left were scared but unarmed and the guard dog, Efa, was seriously shaken but otherwise unhurt. Instead of decoys, what were left was craters meters wide and smashed smoldering buildings (**Figure 8-9**).

Figure 8-7: 3rd battalion peace time position hit b the first night of bombing. Stationary objects were hit but all mobile equipment was relocated before the attack. (Source: NATO)

Figure 8-5: Pre and post strike on 3rd battalion primary firing position on March 24 (Source: NATO)

The battalion absorbed the initial impact without the human casualties. Stationary objects, as

predicted, have been destroyed and there was nothing that can be done to protect them. The decoys worked very well. Seem that the pilots and weapon system operators in the attacking airplanes did not make any differences between the real technique and decoys. A loss of 80 combat ready 5V27D missiles was hard and the question is why those missiles have not been relocated earlier. The price of the single missile at that time was 85.000 US$! In October 1998, battalion command requested permission from the brigade HQ to relocate all missiles to the alternative locations, but the permission never came. Something in the upper commanding and organizational structures didn't work very well. That will happen occasionally during the duration of the conflict.

At this moment, it is necessary to pull the parallel with the initial hours of the operation "Desert Storm" and first air raids. Yugoslavs deployed all stationary and mobile missile batteries to the reserve positions avoiding initial impact which destroyed significant numbers of Iraqis units. Stationary radar installation from the Air Surveillance, Informing and Guiding service (Sluzba Vazdusnog Osmatranja, Javljanja i Navodjenje – VOJIN), warehouses and other stationary objects were hit and destroyed but the majority of equipment has been relocated. However, not everything was dislocated due to the negligence and initial disorganization. VOJIN branch was first to be pounded (**Figure 8-10**, **Figure 8-11**).

The biggest issue in this beginning stage of the war was the communication problem. Deployment to the reserve position, lack of communication equipment and ban of radio links caused that the battalion could not establish the connection with the brigade HQ. The solution was to use civilian lines from the UNK cabin. The radio link was unsecure and never used during the war because of potential jamming and possibilities that the enemy can located the source. The other way of communication was through the field phones which were immune to the electronic jamming. The battalion had only one cellular phone with was used by the commander, Lt. Col. Dani Zoltan. Intervention of the local entrepreneur the battalion got the civilian phone link which was extensively used and was never jammed. It seems that the RAF during the battle of Britain had a far better communications that Yugoslav air defense 60 years later.

That night battalion has been visited by one of the Air force commanding generals, Colonel-General Ljubisa Velickovic. The general was angry why missile units not downing enemy airplanes and why they don't use radars more. It is evident that top military commander had no good idea how missile battalion

works and what are the rules of engagement. This was more or less issue through the whole duration of the conflict.

Typical combat shift lasts for 6 hours than the crew retreat for rest. Depend of the available number of operators and shift commanders the crew had one combat shift per 24 hours, but it was not always like that. First few days the crews took time to adjust to the real war conditions and to get into the war condition routine. The only chance that inferior air defence has is to perform tactical maneuvers and try to catch the superior opponent of guard.

Yugoslav Air Defence (Protiv-Vazdusna Odbrana – PVO), in the time before the outbreak of the civil war in 1990 has been considered an elite branch of the military. The education and training system were based on the Soviet doctrine because the use of the entirely Soviet made weapons system with some sporadic use of western equipment such as long-range surveillance radars. Training in the military academy and school for the operators and technical military academy for the engineering staff provided solid base for the effective air defense. However, years of isolation and economic sanctions took a toll on the cadre. Fortunately, air defense still possessed considerable manpower and technical knowledge.

What one inferior air defense can do against technically far more superior enemy is to improvise. Some of the tactical unit commanders applied this improvisation and achieve success and some didn't. The price that 250th brigade paid in human casualties was not the small.

Improvisation, tactical maneuvers and thinking out of the box was three key elements of survival. It was very well known in the military circles about the capabilities of NATO aviation. By all means, in the war against Yugoslavia, NATO is going to apply the same tactics like in the Gulf War. It was sure that the leading attack will be by cruise missiles, stealth bombers, fighter-bombers with support of electronic countermeasure airplanes and fighter escort. The question was how to absorb and deflect the impact with minimal casualties.

Unit commander and deputy commander knows very well that the highest risk to the missile system crew is the attack of anti-radiation missiles and laser bombs. It was very well known that the attacks on the missile battery will start with anti-radiation missiles. The question was how to protect the crew against these kinds of treat. There was no a single armoured missile command vehicle

for SAM-3 in the whole air defence which can provide protection against anti-radiation missile fragments. Lt. Col. Anicic, studying the effects of HARM got an idea to improvise cabin protection with wooden logs, not just any kind of logs but acacia logs. From the local farms, it was collected about 50 logs, 4.5 - 5 m long and 35-45 cm thick. The logs must be the raw one. The reason for the certain length and thickness is to cover the cabin but not to interfere with the operation of the radar and the thickness is for the easier transport and the acacia log with that thickens will have enough stiffness and at the same time toughness to the high velocity HARM fragments (**Figure 8-12**).

March 26

During the morning hours of March 26 one of the NATO reconnaissance airplanes flew at very low level, approximately 500 m, almost directly above the battalion positions. It was reported that the airplane was French Mirage. Almost immediately the combat shift let the command van UNK. It was opinion among the troops that the position has been located and that the air attack that night is imminent. In that moment, it was obvious that the fire position needs low level air defence. All battalion Strela-2M shoulder launch systems were positioned 10-15 kilometers away, in the direction of potential cruise missile paths. It was evident that the battalion fire position is extremely vulnerable, especially during the deployment from marching to the combat conditions, without short range shoulder launch missiles.

What was the evident in the first few days of war was that there was some kind of mistrust between the field units and the brigade command on some level. In general, with the exceptions of few high ranking officers, most of the brigade command officers worked strictly by the book - very typical soviet doctrine which may be applicable in clearly defined, interlocked and highly saturated space covered with the numerous mobile and stationary missile systems which cover from low altitudes to very high altitudes and hundred kilometers in depth but in the case of Yugoslav conditions that way of thinking presented clear and present danger especially to the tactical units. During the war, tactical units who worked as per very well-known templates were taken out one by one with human and material casualties.

Yugoslavia didn't have strategic depth and airspace defense in jurisdiction of 250th missile brigade was extended to cover the all possible directions toward the capital Belgrade, for which 8 battalions were simply not enough. In these conditions, the 3rd battalion got into the fourth day of war.

The first few days the unit didn’t have any engagement and majority of the works was in proper dislocation and securing the conditions for the combat engagements on the reserve positions. In the meantime, reserve component of the unit started to arrive.

The typical combat crew shift is 6 hours long. Combat readiness No. 1

means that the all equipment is “on”, operators are at their places and the battalion is ready for the combat engagement. During the morning shift, two Yugoslavs MiG-29 took-off from Batajnica airbase near Belgrade and they were observed on azimuth 270 flying in direction of Tuzla, Bosnia. 250th brigade Operation center issued warning to the battalion to not engage and open fire and let MiG’s through their sector. Coordination between air-defense fighter airplanes and missile units is crucial; otherwise missile units may open fire on their own airplanes, which happened in other conflicts before. Very well trained crew will let own airplanes and engage the enemies. The crew followed MiG’s on surveillance radar until they disappeared from radar over Bosnia. What actually happened, two MiG’s were intercepted and downed shortly after and both fell on Bosnian territory.

In the UNK, the crew wandered how come that MiG’s went to Bosnia. It is evident that at the beginning there were some mistrust between operation unit and the brigade command, something that will plague relationship later (**Figure 8-13**).

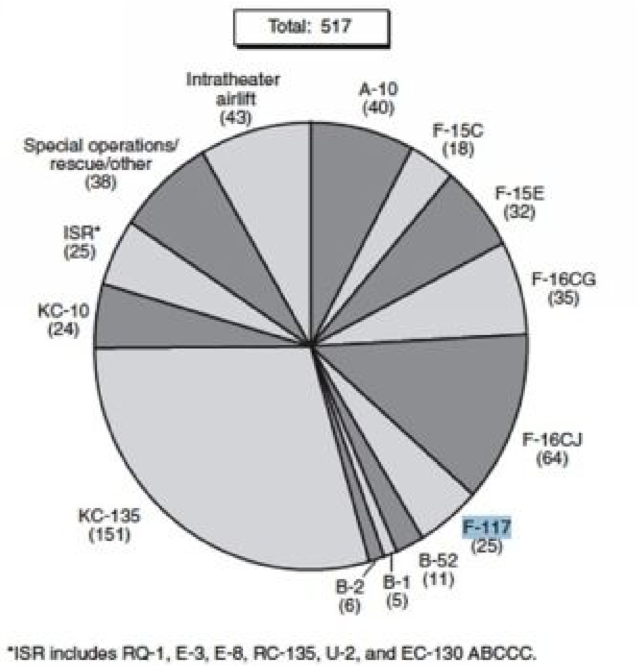


Figure 8-1: US order of battle
(Source: AWOS Fact Sheet via ausairpower.org)

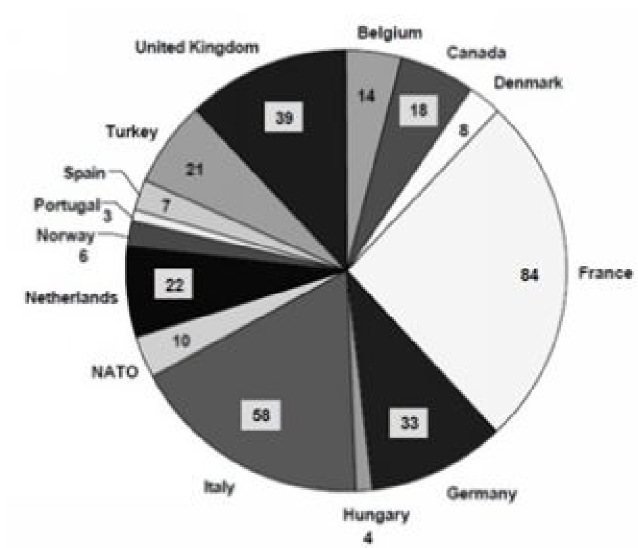


Figure 8-2: NATO countries order of battle (including UAV)
(Source: ausairpower.org)

Figure 8-3: Lt Col Waltering, CO of 8th squadron during Middle East mission.
(Source: USAF)

Figure 8-4:F-117A   taking off from Aviano on March 24.. (Source: USAF)

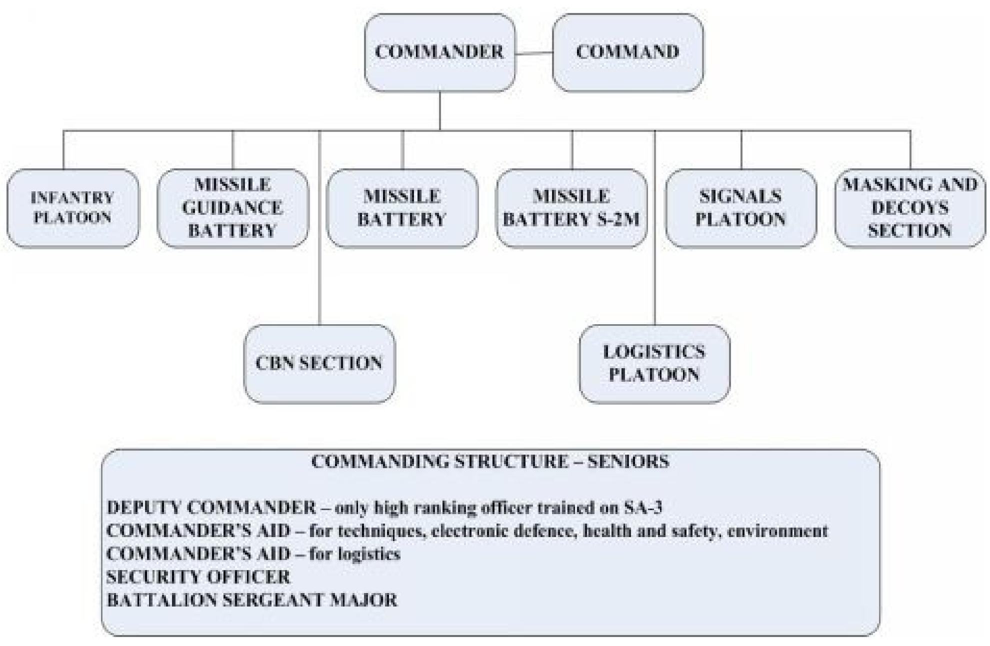
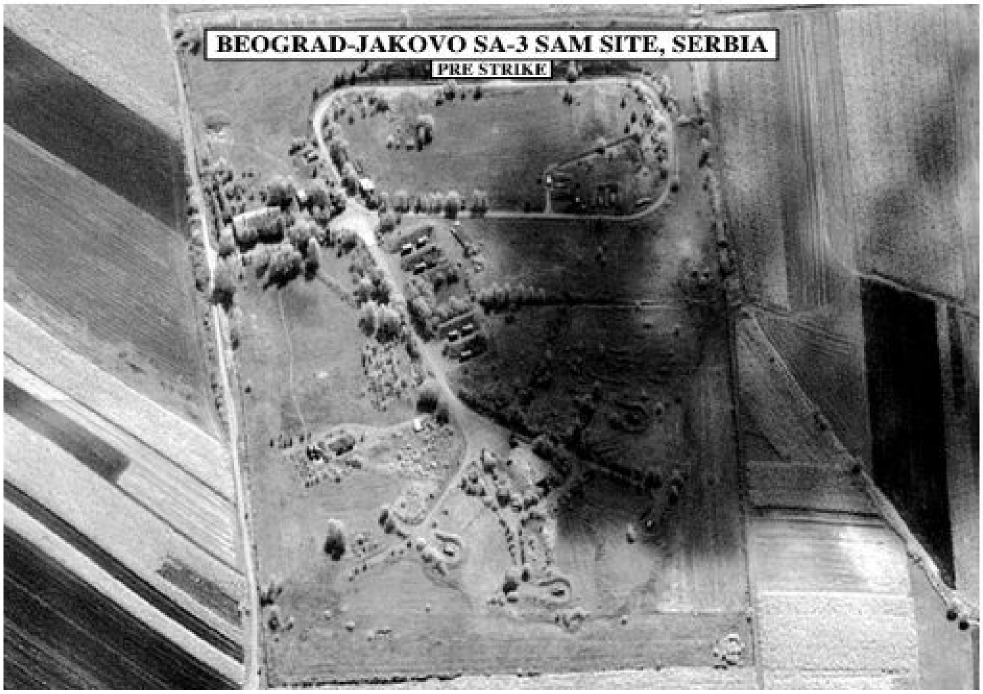


Figure 8-5: 3rd battalion structure (Source: authors)

Figure 8-6: Reserve firing position Simanovci (Source: authors)

Figure 8-7: 3rd battalion peace time position hit the first night of bombing. Stationary objects were hit but all mobile equipment was relocated before the attack. (Source: NATO)


BEOGRAD-JAKOVO SA-3 SAM SITE, SERBIA
PRE STRIKE


BEOGRAD-JAKOVO SA-3 SAM SITE, SERBIA
POST STRIKE

Figure 8-8: Lt. Col. Waltering (8th squadron CO) in the middle, after the first mission over Serbia. In his left hand is the bomb clip which was pulled from the laser guided bomb just before the bomb bay is closed. F-117A pilots, as unwritten rule, kept one of the bombs pins as a souvenir or for the good luck. (Source: Msgt Don Blewett)

Figure 8-9: What was left of the UNV decoy - fully served purpose. During the war, many decoys were hit by NATO bombs. (Source: authors)

Figure 8-10: What was left of the 5V27D warehouse (Sgt. Matic is standing on the concrete block. (Source: authors)

Figure 8-11: 3rd battalion men inside the missile warehouse hit by the laser bomb on the first day of war. (Source: Cedomir Ljubinkovic)

Figure 8-12: Improvised UNK cabin protection with wooden logs.
(Source: "Smena" (The Shift))

Figure 8-13: Serbian Air force MiG-29 crash site in Bosnia.
(Source: Wikimedia)

March 27

Daily “routine” has been established. Combat shifts changes are regular in 6 hours intervals. Lt. Col. Anicic was in the shift until 12:00. After his return to the resting area, he was called up by the courier from the brigade headquarters with the verbal orders to go to the three decoy locations and in the period from 14:00 until 20:00 to use radar imitator and perform the emissions. The idea of the brigade HQ was to use radar imitator to simulate the work of tracking radar. Brigade HQ was sure that NATO ELINT airplanes will pick up emissions and possibly plot the approximate location. Moving from one location to another and emitting simulated radar emission in the 20 minutes intervals may create the false pictures that there are more tracking radars thus meaning presence of other missile batteries around. NATO will record all positions and if the decoys work as planned, the area will be plotted as a SAM sites. Mission planners will plot the locations and they will be implemented into the aircrew’s flight computers as potentially dangerous zones thus to be avoided. As the real battalion was in complete radio and radar emission silence, the hope was that it will wait in ambush for unsuspected airplane to appear in the zone of engagement while avoiding false SAM areas.

The plan was to use location No. 1 Subotiste and perform 20 minutes emissions on azimuth 270, then move to the location No. 2, Pecinci and perform the same task on azimuth 270 for the same time, then relocate to the location No. 3, Dobrinci and perform the emission on azimuth 230. The task shall be executed by 20:00 than the radar imitator will be positioned in the proximity of the battalion and use as a decoy. Lt. Col. Anicic as a deputy commander and battalion XO was also scheduled to take the combat shift at 18:00, so the timeframe was tight to perform all assigned tasks and get to the combat position on time to take over the shift (**Figure 8-14**).

Radar emission imitator is an electronic device which main purpose is to create and emit electromagnetic energy at the same frequencies and wavelengths as an engagement and fire control radar used in missile guidance. There is a great probability that these “false” radar signals may be picked up by ELINT aircraft and fighter-bombers which carry anti-radiation missiles such as HARM. The decoy may attract the missile and force her to fly off from the real radar (**Figure 8-14**).

It is obvious that the emission of decoy from the alternative location created the desired effect. NATO was very aware of existence and the capabilities of Yugoslav decoys. Above all, they have those kinds of devices too, but they couldn't determine are those emissions from the real radars or imitators. If the emissions are not scheduled as a pattern of 20 minutes but random, they may appear more realistic.

During this mission, Lt. Col. Anicic stopover to find the flashlights and inserts through the local territorial defence headquarter. What was chronically plagued the battalion during the entire war was that they were constantly faced with the shortages of many simple items such as flashlights, necessary to operate in the field conditions. The role of battalion deputy commander, beside the combat shifts, was also to deal with these issues as well.

In the meantime, at 18:00 combat his crew took their evening shift and because Lt. Col. Anicic was absent, Lt, Col. Dani continued his previous shift as a commander until the return of Lt. Col Anicic. Maj. Boris Stoimenov took over the position of the deputy combat crew commander with the new crew. The combat readiness was No. 3 which is the lowest one, usually when there are no activities in the air. The crew is in 15-minute readiness. During the previous shift, it was noted that there is a problem with P-18 radar receiver because there was no any picture on the screen below 60-70 km. After the conversation with the commander, Maj. Stoimenov, who was also battalion technical officer, went to the radar van and together with the radar crew tried to fix the problem. There was an issue between parameters of signal and cluster. Maj. Stoimenov reported to the commander that the repair may last for about 90 minutes. Sgt. Ljubenkovic and Maj. Stoimenov worked on equipment adjustment without turning on high voltage and radar emission. After the repair, Maj. Stoimenov requested from Lt. Col Dani to turn on P-18 for the final adjustment and tune-up. He was back in UNK at 19:20 and report to Dani that the radar is ready, but that receiver also needs to be adjusted. Because the probable attack has been expected from the west, radar antenna was positioned on azimuth 90^0 and emission was turned on. After the final tune-up the high voltage was turned off.

Situation was quiet, nothing on the radar screens. In the first few days' air raid alarm usually sounded around 20:00. That was the local time where NATO airplanes were approaching designated targets and were picked up by surveillance radars and visual observation pickets.

Lt. Col. Dani got the information from the brigade command to put the crew into the readiness No. 1 around 19:35. Missile guidance station (StVR in the local terminology) and radar P-18 are turned on and the crew performed the final parameters control and check-up. In the Combat readiness No. 1, the crew is ready to engage the target on momentary basis.

Combat procedure requires that the crew is in constant communication with the brigade command center. Position of the commander is in the front of the P-18 screen (VIKO) (see the schematics for the precise location of the combat positions in the UNK van on **Figure 8-19**). Beside him, sits deputy commander and both can see the radar screen. Every turn on radar screen show that there are airplanes in the air…but they were far away.

UNK of S-125M is very cramped space; with the comfort of the crew was the last worry regarding to ergonomics. Chairs are all but comfortable; humming noise from all electrical equipment is a bit loud; not effective air-conditioning, just a fan to move the air, smell of uniform, muddy boots and unwashed bodies…all in all, not really pleasant working space and environment. In that space, six officers and NCOs performed their tasks.

23 Seconds

Missile battalion combat crew is a team…every member of that team plays his role, and all roles are critical. If any member of the team does not perform his duty, that mean the whole team fail…and in the war circumstances, that often mean that the complete or partial team is eliminated, together with their combat station.

The life of combat crew during the engagement is measured in seconds. That is how much is necessary to fulfill the mission or die trying to do that.

In ordinary life seconds does not mean much, but for the missile operators that is the crucial difference are they going to bring down their target or be shredded to pieces by anti-radiation missile or laser bomb.

On the evening of March 27, the crew consisted of Lt. Col Dani Zoltan, commander, responsible for all performing in UNK; Lt. Col. Djordje Anicic, battalion deputy commander and XO and assigned shift commander arrived at 20:30, responsible for all activities out of UNK such as power supply, radar, communication, signals etc.; Maj. Boris Stoimenov, until the arrival of Lt. Col. Anicic deputy crew commander; Capt. I class, Senad Muminovic, fire control officer; Sub-Lt. Darko Nikolic, battery commander; Sen. Sgt. Dragan Matic, manual tracking operator on F2; Sgt. Dejan Tiosavljevic, manual tracking operator on F1; private Davor Blozic, clerk and manual plotting board operator. Beside the combat crew in UNK detached trucks with power source pack unit (Sen. Sgt. Djordje Maletic and pvt. Sead Ljajic) and P-18 early warning and surveillance radar station (Sgt. Vladimir Ljubenkovic and pvt. Vladimir Radovanovic) also performed critical role (**Figure 8-18**).

What was unusual that evening, and something that will never repeat again in the combat situation was that in the moment of engagement, there were two commanders in the UNK. Combat rules of engagement and procedures allow only one commander but in the war circumstances it may be different. Lt. Col. Anicic returned to his post at 20:30. At that moment there was no combat engagement, but missiles were in the Readiness No. 1 on the ramps ready for launch and no combat readiness in the station which is very unusual (why we'll see in the next section). The night was clear. Moon light reflected on the stand-

by missiles on the launchers.

When he entered in the UNK (**Figure 8-26**), Lt. Col. Dani was lean on the electronic control blocks by VIKO, seem to have a rest. Maj. Stoimenov raised and moved behind the fire control officer so that Lt. Col. Anicic can take the sit (as a senior officer and his shift commander). Anicic took over the headset with the microphone which is used to be in direct contact with the brigade operation center. Technically, as Lt. Col Anicic entered into the UK, he is in fact the shift commander and taking the position with his shift which came earlier, and Lt. Col. Dani is about to leave after they exchange thoughts of the day reflecting activities in the battalion and the individual tasks. (**Figure 8-15**). Lt. col. Dani is still sitting in the shift commanders place until formal duty handover and Lt. Col. Anicic set at the deputy commanders chair. When lt. Col. Dani leave in a few minutes, Maj. Stoimenov will take the position of the deputy commander. It was routine procedure that the previous and new shift commanders exchange information in the duty handover. There was no formal military reporting to each other, rather was more conversation.

While two officers talked about the afternoon situation and performed tasks, Lt. Col. Anicic faced P-18 screen directly and clearly saw what is going on the radar screen. Lt. Col. Dani is turned sidewise and not facing the screen this time. P-18 radar screen on VIKO showed that there are airplanes in the air...but still out of range on different azimuths, somewhere in vicinity of Belgrade. Radar imitator that Lt. Col. Anicic brought back from the field is not yet connected. (see illustration presenting UNK layout with exact position of every crew member on **Figure 8-19**).

While exchanging thoughts of the day about the situation in the unit and performed tasks, suddenly the surveillance radar showed three blips at azimuth 195, distance 23 km. Lt. Col. Anicic followed three more sweeps when he saw that one target got 17-18 km from the radar. He then informed Lt. Col. Dani about the blip on the radar screen (**Figure 8-18**).

“Dani, this guy is going toward us.”

Dani quickly opened his eyes and looked at the screen. The next sweep showed that the blip was now 14-15 km away...approaching…After two more radar sweeps Lt. Col. Dani ordered:

“Azimuth - 210… Search!”

S. Lt. Nikolic, battery commander started to turn control wheels on his UK-31 plan position indicator and the start zone (part if UK60 station) in attempt to guide the missile guidance officer by azimuth and elevation:

> *"To the left…to the left stop!...right…up…up…up, stop!*
> *"Antenna!"…*

At this moment the fire control radar is turned on.

The cat and mouse game started…Whoever is faster and more agile – wins!

Battery commander guided the fire control officer to the target. Capt. Muminovic, fire control officer on his UK-32 station (indicator of guidance and manual tracking by range, part of UK30 station), franticly turned three wheels at the same time trying to find a target…His first attempt was not successful and on his screens, he was not able to see the target and handover to the manual operators. The target had high angular velocity, maneuvering, and that may the reason why the operators were not able to start tracking. The fire control radar emission seems too long. The target most likely got the warning signal in his cockpit that he is illuminated by the engagement and fire control radar.

The cumulative time since the target was detected, fire solution acquired, firing command issued, missile launched and target intercepted must be 25-27 seconds maximum. Anything longer and the station will be hit by anti-radiation missile. That was the time AGM-88 HARM need to fly from the launching airplane to the radar.

The tension was in the air…

As the fire-control radar emission was 10s long, Lt. Col. Anicic ordered:

> *"Stop search - Equivalent!"*

Sub Lt. Nikolic didn't hear that command or he might be confused because two combat shift commanders issuing the orders. Lt. Col. Anicic ordered much louder:

> *"Get – the – High - down!!!"* and Lt. Nikolic immediately turned it off:

> *"High - off!"*

Few seconds later - the next attempt...Lt. Col Dani ordered:

"Azimuth – 230 - Search!"

The guiding station was saturated with the humming noises from the electrical equipment and clicking of the switches and wheels and commands. This time guiding officer was able to see the target on both screens. Metal wheels clicking…Capt. Muminovc pushed the wheels hard forward to get the target in the crosshair of his two markers but after few attempts he was not able to put the target in the intersection of the horizontal and vertical markers. When the target is in crosshair of both markers he can transfer to the manual tracking operators on F1 and F2. The second attempt was when the target was approximately 14 km away.

Again, radar emission was a way to long and Lt. Col. Anicic commanded:

"Stop searching - Equivalent!!!"

Lt. Nikolic responded promptly:

"Equivalent!"

Few seconds later, Lt. Col Dani ordered:

"Azimuth – 240 - Search!"

The third attempt on target was when it was 12 km away.

A couple of seconds later, guidance officer found the target and it was clear that the target is maneuvering. The Clicking of the wheels and again the target is escaping…emission was 5-6 seconds and Lt. Col Anicic told to his commander.

"Dani, be careful, we don't want them to screw us"

The reason for this concern was that airplanes may use decoys, in some case towed decoys which represent large reflective surface that can confuse the radar operators and mask the real target.

It happened during the first Gulf War that Iraqi crews had the decoy target on their radar screens, locked their firing parameters just to be hit by an anti-

radiation missile fired from the side by one of the fighter-bombers equipped with HARMs.

Lt. Col. Anicic was about to issue an order to stop search again because the search time is too long, when the operator for the manual tracking on F2, Sen. Sergeant Matic (**Figure 8-17**) vigorously turning his wheels in attempt to get the target in the center of his crosshair on his screen. Sergeant Matic yield:

“Give it to me! Give it to me!...I have him!!!”

At that moment Cap. Muminovic pushed his wheel forward and handed over the target to the manual tracking operators.

"Track manually!"

Figure 8-17: Sgt. Matic at his combat position on F2 (top picture) and missile guidance officer screens(bottom picture) (Source: authors)

Sgt. Matic locked the target on F2 crosshair on his UK-33 screen…and that was it...he got him!

The second operator on the manual tracking on F1, sergeant Tiosavljevic, got the target on his screen markers too. The screen reflection was very big. The target is “caught” and both manual tracking operators have it on their screens.

Capt. Muminovic reported that the station has stabile tracking, the target is in approaching path…distance to target 13 km. Both F1 and F2 operators reported that they have stabile target tracking. All parameters for the firing solutions were achieved.

"Station tracking target, target in approach…distance 13 km!"

Operators reported:

"F1 manual tracking on!"
"F2 manual tracking on!"

The battery commander didn’t reported target engagement probability but Lt. Col. Dani still commanded:

“Destroy the target! Three point method!... “Launch!!!”…

Capt. Muminovic pushed the start button and the first missile engine started and the missile blasted off from the launcher.

“First missile launched - first missile tracking! (both F1 and F2 operators manually guide the first missile).

After 5 seconds the second missile blasted too. The noise of launching was so loud that everybody in the surrounding area, including the base camp heard it. Gravel beneath the launchers was blown with the rocket engine blast and hit the UNK van like shrapnel.

“Second missile launched - second missile not tracking!!!"

As both F1 and F2 operators reported stabile manual guiding for the first missile the second missile didn’t acquire the target and the tracking was lost. The first missile was 5-6 second in flight and 10 more seconds to the interception point. F1 operator reported that the target has large RCS.

Lt. Col. Anicic rose from his seat and looked over the manual tracking operator shoulder:

“How come it didn’t catch the target?!! Why?!!”

The first missile was on the stabile trajectory to the target but the second one lost the contact with the station and continued on the ballistic trajectory, away from the target.

The crew looked the last few kilometers before the missile reach the target… Than the large flash blips on the missile guiding officer’s screen. The missile reached the target at 20:42…Target destroyed… The interception has been at 8000 m altitude. The target was acquired at 6000 m. Obviously, the pilot saw the launching or has been warned that he was illuminated by the fire control radar and tried to perform anti-missile maneuver but once locked, there was no chance that he can avoid hit. The whole operation lasted about 23 seconds…(**Figure 8-20**, **Figure 8-21**, **Figure 8-22**, **Figure 8-23**).

How missile battalion works

Roles and duties of SA-3 missile battalion and its members are defined and regulated through the operation and service manuals issued by the Ministry of Defence, and Air-Defence branch of the armed forces. Basically, it is based on the Soviet military doctrine for the same type of units with some minor local modifications. Subjects of these manuals are not much different with the western counterparts and includes combat service, organization, system equipment, communication, safety, transportability, reconnaissance, selection and occupation of positions, to mention few.

To have a fully trained and functional missile system combat crew, the years of trainings and exercising are necessary. In example, for an officer, directly from the military academy, to get to know every single component of the system and to be fully familiar, a minimum of 5 years on the designated system is necessary. For a commander, 10 years of work on the system is a necessary minimum. As we saw previously, only Lt. Col Anicic was the one with such experience. Other officers were trained for other systems but still had some experience on SA-3, thanks to the intensive pre-war trainings and exercises on the ARRENA simulation and training system (**Figure 8-25**).

In peacetime conditions, in the missile battalions classified as an "A formations" there are two combat crews which were fully trained and checked through the following:

- AKKORD - specially designed realistic combat simulator cabin (identical copy of UNK station) for simulation of different combat scenarios);
- Training with own air force during tactical exercises and combined tactical trainings and
- Unit deployment o from primary to reserve fire positions.

Typically, the first combat crew includes the most experienced and trained staff comprised of four officers, two non-commissioned officers and two enlisted servicemen. The peacetime formation of the combat crew consists of: shift commander - unit commander as a shift commander, the deputy commander

(XO) is the deputy shift commander, missile battery commander (on the missile preparation station), missile guidance officer, manual tracking NCO on F1 and manual tracking NCO on F2. Two enlisted servicemen manned the manual plotting table and fire control plan as well as shift register. the roles of each member of the crew will be explained in detail in the further text.

In some peacetime exercises, depending on the location of the P-18 surveillance radar and in order to reduce the engaged number of people, it was possible to consolidate the duty of the shift commander and the deputy commander in one role. In the war conditions this was not acceptable, nor the SA-3 combat procedures allow that. Some of the missile battalions acted on this way with a reduced combat crew consisting of 3 officers and 2 non-commissioned officers and without the enlisted men. This fact later leads into the dispute among missileers even at higher levels of command. one of the reasons why this happened was that there were some "older cadres" which were trained on SA-2 systems in which the manuals and rules of engagement does not consider the position of a deputy shift commander. We will solve this dilemma when we come to the consideration of the duties of the shift commander and the deputy shift commander. The designer of SA-3 system in the rules of employment and engagement, established the formation position and role for the deputy shift commander to achieve optimal combat crew number necessary to carry combat duties (**Figure 8-27**).

The reader shall not be mislead that the only above mentioned positions are engaged in the combat duties. Previously mentioned roles are only for the missile guidance station where all information are channelled and where the target acquisition, fire control solution and missile guidance is prepared and executed. The number of other combat positions is far greater and includes all support units and staff.

Figure 8-26: 3rd battalion UNK missile guidance station (van). (Source: authors)

The war conditions dictated a completely different way of combat employment. The activity of NATO aviation was all day around the clock which required the continuous standby and rotation of people and equipment in the combat readiness No. 1 and no. 2. Equipment was ON sometimes even 22 hours a day and with the minor breakdowns we can say that was more or less reliable. These conditions required the formation and employment of two combat shifts. This created enormous psychological and physical stress to these two combat shifts who were constantly rotated every six or eight hours.

The first combat crew was commanded by Lt Col Dani, as a commander with the formation assigned battery and missile guidance officers and NCO operators. For the second crew, the commander was battalion XO Lt Col Anicic with the non-formation assigned offices that held some other commanding duties within the battalion when not assigned to the combat shift.

In order to save one life in the event of a missile strike into the station, one of the enlisted servicemen position, fire control plan and register, was eliminated. That position was taken by a serviceman who controls the manual plotting board. This manual plotting board was used only in the initial period of the war until NATO degraded the airborne surveillance and guidance system (VOJIN). The data about the situation in the air received from them, had a few minutes delay which is basically useless by the time is received in the battalion command center. In these few minutes delay, the situation in the airspace can change drastically. The brigade commanded insisted at the beginning of the war that this station must be manned in all subordinate units and the crew commander or the serviceman manned the station to report through the communication link what they see at the plotting board. This mistrust by the presumed command further aggravated the combat service. Very soon after the battalions got hit by the HARM missiles or laser guided bombs from the SEAD groups, this position and practice is terminated. Soon after, the other enlisted positions in the power generation station and P-18 radar are eliminated too. Since then up to the end of the war, the fire control station was manned only by 4 officers and 2 NCO's. Power supply station and P-18 radar were not manned during the combat engagement, but the operators were very close in the case that their presence in the station was necessary. This reorganization and reduction of the people that can be directly exposed to the enemy fire reduced the combat casualties in some other battalions.

The 3rd battalion has an impressive war record: during the 78 days of combat, the unit changed combat position 22 times and passed 100.000 kilometres. The unit engineering section built 11 brand new combat position. The unit has been targeted with 22 anti-radiation missiles which remains were found. It is possible that it was targeted more but the missiles remains and fragments were not found. Not a single missile ever hit any object and not a single battalion member was killed or injured. This is the only unit in the 250th brigade with this record. Success of the battalion includes two confirmed kills: F-117A and F-16CG which crashed in the Serbian territory. on the night of May 19/20 a very large aerial target was hit and beside there is no material evidence

that the target crashed in the Serbian territory, there are a lot of researches and indication that the target was one of the large aircraft. At the time, only three large aircraft used in bombing of Yugoslavia were B-2, B-1B and B-52. This will be analyzed in the next chapter.

Applying the rules and manuals of engagement, with some field innovations and modifications at the insisting of the battalion XO, the combat roles of every combat crew member were clearly identified and not a single time the battalion lost the connection with the brigade command, properly informing about the situation in the designated area, or unnecessary exposed themselves to the enemy and also always been aware of the own airplanes in the designated airspace and in the vicinity of the Batajnica military airport and Surcin civilian airport.

We already saw that the battalion may have 3 stages of readiness. Combat readiness No. 1 means that all equipment is powered and at least two missiles are in the combat ready position, ready for launch. Missile station and other equipment is tested for functionality. Shift commander than reports that the battalion is in the full readiness with 2 channels in combat readiness with two, six, eight or more missiles. All communication is going through landlines.

Missiles at the firing positions can be held in the following positions:

- Transport position on PR-14 vehicles,
- Loading position,
- Duty position - on the 5P-73 launching ramp,
- Combat position on the launching ramp.

In the combat position to transfer the missile from the "stand by" into the readiness for launch an interval of min 30 sec is necessary. Command transfer is executed from the UNK with the button switch. In this regime, the maximum duration time for the missile to be ready for launch is 25 min after which the system automatically turns it off. There is embedded system restriction that the missile must be 20 min in off mode before is transferred again to the 30 sec. regime. The one cycle of the missile preparation includes 25 minutes in "ready for launch" and 20 min in off position. After that, the cycle starts again. There is a possibility in the case of emergency, that the missile can be turned on in the launch position and that is regulated in the missile maintenance and use manuals (**Figure 8-27**).

Readiness No.2 means that the crew is in combat positions, equipment is powered but is in the "off" stage with the manual switches in the "off" mode. Temperature of the oil and coolant must be higher than 37 degrees.

Readiness No. 3 means that the crew is in the base camp with 15 min readiness. That men that the crew must within 15 min be ready to get to the position, turn and test the equipment functionality and report that it readiness for the combat.

"Ready for launch" is when the brigade assigns the target to the battalion or in the case for the sudden appearance of any target in the assigned sector. missile is ready for launch. It is basically the same as readiness No. 1 just in this case at least four missiles are ready for the immediate launch on two different launchers. Missile are turned on readiness No. 1 in 3-5 seconds intervals, about 30 seconds before the functionality of the station is finished.

"Rapid readiness for launch" from the readiness No. 2 is executed in the manner of getting into the readiness no. 1 with the exception that the functionality of the station is executed until the fire control radar is turned on with the high voltage which turns off functionality check and immediately the fire control radar starts to search for the target.

Because there is time frame restriction for how long missiles can be in "ready to launch" stage, for the commander is crucial to determine when and how missiles readiness may be distributed. The last thing that the commander want is to have a target inside the engagement envelope but doesn't have the ready missiles on the launchers. The golden rule is not to put the missile into the launching readiness unless the target is within the engagement zone.

Combat crew - the shift

The role of every member of the combat crew is crucial and every member has predetermined role. Formation determined working station and places are as follow:

- Combat shift commander
- Deputy combat shift commander
- Battery commander
- Missile guidance officer
- Manual tracking operator on F1
- Manual tracking operator on F2
- Manual plotting board operator
- Fire control plotting board operator and shift clerk

Every single work place has determined role and not all positions are engaged in the same time. Commands and reports are overlapping and for the well trained and synchronized crew that does not present any obstacle. The goal is that within 25-27 seconds the aerial target must be engaged and downed.

On the night of March 27, the situation in the UNK was the following:

Combat shift commander

The working position of the shift commander is in front of the detached P-18 radar screen (VIKO) which is on his right-hand side. Workplace is raised about 32 cm in comparing to the other crew members working stations. This allows the shift commander to have unobstructed angle view to the rest of the cabin, excluding the position of the manual tracking operator on F1. Behind the commanders back there are electronic blocks that control missile launchers. The commander position is intentionally designed on this way so that the deputy shift commander also have the clear and unobstructed view of the detached P-18 radar screen and this allows two members to look and control airspace. Rules of employment directs that at least battalion commander, battalion deputy commander (XO) and missile battery commander must be fully trained on SA-3 system. On the other words, doctrine calls that three key members of the battalion must know the systems as "a palm of their hands". The 3rd battalion had two trained crew commanders - battalion commander and XO. Missile

battery commander was not fully trained as a crew commander. As the battalion commander was often absent because of the other obligations, the battalion logistic commander was trained for the duty of the shift commander. He was not checked by the brigade command, but he was fully trained and with a lot of experience on SA-2 system. He was partially familiar with SA-3 system equipment (**Figure 8-28**).

The combat shift commander must command as per directives of the combat procedures manuals and fire control manuals which includes:

- Control the airspace through the detached surveillance radar (VIKO) screen from the P-18 radar.
- Issues an orders for target search, starts and stops the search in the designated sector taking in consideration durations - critical for operation,
- Issues an orders for tracking the designated target, issues order to launch missiles, determines the missile guidance methods, numbers of missiles, launch methods, warhead activations,
- keeps communication link with the upper command

Combat shift deputy commander

The working place is beside the shift commander, on his left-hand side, right at the side entrance. The position is directly facing the VIKO screen. Deputy commander has unobstructed clear and ergonomic view at the screen. Some of defined roles includes:

- Together with the crew commander controls the airspace through VIKO screen
- Marks the potential target and assigns priorities using charts and nomograms (diagram representing the relations between three or more variable quantities by means of a number of scales)
- Determine the primary target
- Commands the interior battalions' units - communications, guards, P-18 surveillance radar, power supply, radar emission imitator etc.

For this position, at the first combat shift, the missile battery commander was designated and in the second shift it was the battalion technical officer.

3. Battery commander

The position of the battery commander is at the missile preparation station. The distance from this position to the shift commanders place is about 2 m toward the mid of the command van and it is farthest officer position from the commander and the deputy commander. In the first combat shift, that duty was performed by battery commander and in the second shift it was the first missile battery platoon commander (**Figure 8-29**).

- Acts as per orders issued by the commander or deputy commander.
- Rise the high voltage at the fire control radar transmitter.
- Turns on and off fire control radar (antenna -equivalent switch).
- Commands/instructs the missile guidance officer to the assigned azimuth and angle trying to get target acquisition radar beam in the same point in which the surveillance radar detected the target. Commands may include left, right, up or down which allows missile guidance officer three to five turns with the wheels on azimuth and angle which were commanded by the shift commander. On this way, the aerial sector is searched in the two levels.
- Determines possibilities for the target engagement based on the circular indicator PKO (**Figure 8-30**).
- Determines which missile launcher will be used.
- Prepares launchers - power control which starts "30 seconds regime" and "preparation 1" for the missiles.
- Command the missile section

The deputy commander and the missile battery commander are two different functions and does not have the same duties.

When the command *"Azimuth 210, search!"* was issued, battery commander, looking on his UK-31 screen, starts to guide the missile guidance officer to turn UNV antennas to the commanded azimuth (in this case azimuth 210). The commands may be right, left, up or down" which depends on which azimuth he directed his fire control radar. The exact position of UNV battery commander can determine based on the instrument scale which is located beneath the UK-31 screen or by the reading directly from the screen in front of him. if the POST was, i.e. at azimuth 180 and he need to direct to the azimuth 210, the command that he need to give is *" RIGHT,RIGHT…"!* As the missile guiding officer moves his wheels to the right, at the battery commander UK-31 screen the line which

starts from the middle of the screen (zero radiation emission line, in the other words emitter, missile battery) and ending at the periphery, shows movement from 180 to 210. When the antenna movement reach 5-10 degrees before the commanded azimuth 210, the battery commander turns the switch "ANTENNA-EQUIVALENT" into "ANTENNA" position and at that moment the high frequency energy is radiated into the space. He then reports to the shift commander:

"ANTENNA!"

With this, fire control radar is emitting into the space and starts illuminating the area where the target is.

Battery commander continues to guide the missile guiding officer: *"RIGHT, RIGHT…"* searching for target up to the azimuth 220. If the target is not acquired, he commands: *"STOP, LEFT.."* until azimuth 200 is reached. That mean plus/minus 10 degrees left and right from the ordered azimuth by the shift commander.

If by any chance the target is not acquired in one sweep, he than command the guidance officer: *"UP!"* that mean sweeping the space at the same azimuth but the different height. Experienced missile guiding officers knows how to swipe the area with 3-5 wheel turns even without the commands from the battery commander. Experienced officer will swipe the area in few seconds, which provides the high frequency emission time shortening. Every time when the battery commander sees on his screen that the line pass over the target and there is a blip he must warn the guidance officer with: *"YOU HAVE TARGET!"* Experience battery commander will do that routinely. Sub. Lt. Nikolic, as fresh from the academy, was not experienced.

At that moment high frequency radiation was far longer and there is a real danger that the position of the radar may be detected and anti- radiation missile launched.

We already saw in the previous section that Lt. Col. Anicic ordered stop with the emission with the command *"STOP SEARCHING! EQUIVALENT! and "TAKE THE HIGH DOWN!"*

When the next command azimuth" is ordered, the procedure is the same.

Missile guiding (guidance) officer

The missile guidance or guiding officer is positioned on the left-hand side from the battery commander. His duties include:

- During the combat engagement acts as per commands issued by the shift commander and battery commander in the different operating regime of the station.
- In the passive regime performs the controls of the designated sector
- Transfer the UNK station into the combat regime
- Acts as ordered by the battery commander searching for the target turning the two wheels on azimuth and angle (elevation) 3-5 clicks left-right or up-down.
- Report to the shift commander about the detected and acquired target.
- Track the target by distance.
- Command the manual operators on F1 and F2 the mode of tracking.
- Perform the missile launch. Reports the target acquisition, guidance and hit or miss.
- Estimate the results.

Behind the missile guidance officer there is a empty space where is only possible to stand full height during the combat engagement. This space during the peace time trainings and exercises was often used by the senior officers from the brigade or military control bodies during the combat crew assessments and evaluations.

In the first combat shift this duty was performed by the formation assigned missile guidance officer. In the second crew this position was assigned to the commander of the transmission platoon from the missile guidance battery.

Missile guiding officer acts as ordered by the battery commander and his main task is to "overlap" the target on his two UK-32 screens, the goal is to get the target into the cross of horizontal and vertical markers. Experience and practice play a great role and can save the vital seconds.

Crew commander must react and stop the search if is too long. If the commander is not reacting than the deputy commander must issue that order. In short, time management is essential for survival.

SA-3 system requires simultaneous manipulation with the three metal wheels

(see the station photo on the previous page). Hand coordination and speed is a key. Capt. Muminovic was not by formation missile guiding officer nor he was experienced working at the same time with the three wheels: azimuth, elevation and distance and it took him longer to acquire the target. We saw that the target was acquired in the third attempt and at that time he was able to track the target.

By the wheels clicking, the commander may determine the condition. Manual tracking operators also on their screen see the target. When the guiding officer push the wheel from himself and command: *"TRACK MANUALLY!"* he transfers the tracking to the manual tracking operators who then track the target. Aldo operator on F2 can acquire the target on his screen and if he has it, guidance officer can transfer tracking.

On the block UK-62 in front of the guiding officer the lights "RS F1" and "RS F2" are illuminated (**Figure 8-31**, **Figure 8-32**).

<u>Manual tracking operator F1</u>

This NCO position is right behind the missile guidance operator. It is located in the "cavity" from the central passage in the very tight space. In the first crew that was the system operator which was also tracking operator from the missile guidance battery. In the second shift that was the system operator (**Figure 8-33**). His duties includes:

- Manually tracking the target as ordered by the missile guidance officer.
- Reports to the missile guidance officer on the tracking conditions.

<u>Manual tracking operator F2</u>

This position is located right beside the shift and deputy shift commander. On his right-hand side is the missile guidance officer. His position allows him that with the half turn he can see the VIKO screen. In the first crew that was the system operator which was also tracking operator from the missile guidance battery. In the second shift that was the system operator. His duties includes:

- Asses the optical visibility on the television optical system (VPU-44).
- Manually tracking the target as ordered by the missile guidance officer.
- Reports to the missile guidance officer on the tracking conditions.

When the missile guiding officer switch the tracking to the manual operators, on their stations the switch "Peredacha na RS", which is original Russian designation and mean "Manual tracking transfer" is illuminated on the blocks UK-68. both F1 and F2 operators must push the button "VKL RS" to activate the manual tracking (**Figure 8-35**, **Figure 8-34**).

Turning their wheels their vertical markers must be positioned over the target center. With this they established the conditions for the missies launch.

<u>Manual plotting board operator</u>

This is enlisted position. He is positioned few meters from the shift commander, behind the 1.5 x 1.5 m transparent plexiglas plotting board). In the working position, it takes almost the whole width of the station. His main duty includes:

- Plot the aerial situation as per information received from the VOJIN service or as per information received from the battalion own surveillance radar (P-18). Information are plotted in mirror so that the shift commander can see the in normal view.

The challenge of this position is that the enlisted man must be capable to write the numbers like in mirror. When the shift commander sees that in the board the target is within the engagement zone he may order the target to be engaged. By modern standards, this manual plotting board is obsolete and as time of this book, not a single one modern air defense missile system uses it.

Fighting sequences

Once when the surveillance radar from the brigade detects the target and assign it to the battalion or the battalion detects the target with their own surveillance and tracking radar, either under direction from the brigade post or independently, the shift commander issues the order to the battery commander, to search with the engagement and fire control radar in the direction of the target and estimated height. That is the meaning of command "**Azimuth (such and such)…Search**". At that moment, engagement and fire control radar is turned on and the high frequency energy is emitting into the space in direction of the target. The target is illuminated with that energy. At the same time when the energy illuminates the target, the receiver at the target detect that it is "caught" and typically the sound informs the pilot that he is "in the radar sight". Energy is also detected by other airplanes in the vicinity.

Typical combat engagement rule and manuals in the Soviet practice require that the engagement of the target shall be at the farthest zone of destruction. What is disadvantage is that the whole procedure extends, and the target has a way better possibility to detect that is on the fire control radar sight. The distance provides the target opportunity to perform counter-missile maneuvers thus lower the probability of missile hit. Also, if the target is equipped with anti-radiation missile such as HARM it can shoot at the direction of radar. As the speed of anti-radiation missile may be higher than the speed of the SAM missile, there is probability that the radar will be hit before the guided missile reaches the airplane.

Because of this, it was wise tactical decision of the crew to let the target to get deeper in the zone of destruction thus limiting the time for the pilot of the target aircraft to react and perform maneuvers and shorten the missile traveling time. For example, if the effective range of NEVA is 25 km, the optimal distance for probable destruction is half of that, 12-13 km. The high frequency energy emission of the engagement and fire control radar into the space is for only limited period of time, 5-6 seconds, which reduce the time for anti-radiation missile to acquire and hit the radar (**Figure 8-27**, **Figure 8-37**).

The Low Blow is designed to acquire targets using only bearing and range inputs from an external 2D acquisition radar, such as a P-12/18 Spoon Rest or P-15M Squat Eye. 3rd battalion has only P-18 radar. When acquiring a target, the

Low Blow radar head is rotated to the target bearing and the UV-10 antenna scanning feed engaged to produce a 1° wide pencil beam swept in elevation (**Figure 8-36**).

During target acquisition, the pencil beam of the UV-10 antenna is scanning a 10° sector vertically. The maximum range for target detection range is 80 km.

During target tracking, the pencil beam of the UV-10 antenna illuminating the target and measuring its range. The two wide beam UV-11 antennas are receiving the target, and missiles (F1, F2) angle. The maximum range for target tracking is 50 km. Two main range modes can be selected, 80 km and 40 km. In 80 km mode, only half of the electromagnetic impulses are sent, as they have to travel double range, compared to the 40 km mode.

Figure 8-39: UNV antenna emissions zones top (Source: SAM simulator) zone interlocking diagram (Source: Soviet S-125M manual

Once the target is acquired the Low Blow is switched into tracking mode, using the UV-10 antenna to transmit, the UV-10 to receive for ranging, and the scanning UV-11 chevron receive antennas for angle tracking. The radar head is mechanically steered in azimuth and elevation to maintain track (**Figure 8-38**).

The Low Blow provides manual tracking, automatic tracking and television angle tracking modes. The system provides five missile guidance control laws, TT (CLOS), PS, MV (LoAlt), K (surface target attack) and DKM (ballistic). Three missile uplink signals are employed, K1 and K2 for pitch/yaw steering, and K3 for fuse control. There is also K6 on the new system S-125M1 in which the range of the missile in pursuit geometry is extended and the warhead activation is delayed until the missile is in the proximity of target providing the fuse activation when the missile reaches the target which increase probability of the side hit. The previous provides tail hit in pursuit. Side hit provides greater probability of target destruction. The main advantage is that with 5V27U missiles the target can be engaged only in the approaching directions related to the missile launchers and with the modified 5SV27D it can be engaged in both approaching and departing directions (**Figure 8-39**).

Russian doctrine in the presence of heavy jamming was often to cease emitting and use the scanning receiver to effect angle tracking of the jammer, acquire the target with the TV telescope, and perform a range unknown missile shot against the jammer in CLOS mode.

Due to the addition of a clutter canceller and analogue MTI circuits, the Low Blow has significantly better clutter rejection performance compared to the earlier Fan Song. Cited low altitude capability is against targets which fly as low as 20 m (~60 ft AGL).

The command “**Equivalent**’ is to “turn off” the high frequency energy emission into the space, but not turn off the radar. This mean the system keeps the equivalent load but the energy is redirected and effectively “encapsulated” into the system and turned into the heat…The generated heat means that there is still energy emission which can be detected by the anti-radiation missile. The command “**Get the high down**” mean that the high voltage is turned off but the emitter is still working in the normal mode but there is no high energy emission into the space. It is the role of battery commander to work on this on his UV-61 station.

Manual operators on F1 and F2 guides the missile on F1 and F2 levels. In the search and guiding regime there are two standard levels – azimuth and elevation and when the command is to start the manual tracking is issued, then there are on levels F1 and F2. Those to levels are positioned 90^0 on each other and 45^0 related to the surface (**Figure 8-39**).

Radar imitator starts emission few seconds before the fire control radar, on the same frequencies, and continues that operation during the entire fire sequences and is turned off few seconds after the fire control radar is turned off or in the “equivalent” mode. This provides additional protection for the UNK because anti-radiation missile may pick up the emission form the imitator and once locked to that direction it is diverted from the UNK.

Disadvantage in the current situation was that the radar imitator crew needs to manually turn the imitator to the designated azimuth, as per order from UNK. It would be a way better if the movement of the imitator is synchronized with the movements of the radar antenna. At that time, battalion had what they had and they had to play with what was available.

What is of the crucial importance for any missile unit is the power supply. UNK, UNV and ramps are useless without the power. SA-3 system power during the operation is provided with the total power of 200 kW which came from 2 diesel generators. During the combat engagement, both generators are connected

in the parallel connection providing dual supply as an extra safety factor.

… immediately after

Immediately after the crew observed hit and disintegration of the aircraft, the engagement and fire control radar is turned off. The standard procedure calls for immediate evacuation of the existing position and relocation to the alternative one, previously chosen. There are wide spread speculations that the crew knew that they are tracking F-117A but that is an utterly nonsense. UNV S-125 engagement and fire control radar and tracking surveillance P-18 radar does not have any ability to recognize what kind of airplane is in the air. It is just a blimp on radar screen and for the missile crew it is a target. No shape can be determined, no type, just the size because of the reflection. For the crew, that was the target that was tracked, engaged and destroyed according to the rules of combat engagement.

Lt. Col Anicic, as per rules of engagement, reported to the brigade HQ about the engagement. That report consisted of the crew, what was the guidance method, launching sequences, missile usage, warhead activation method, and as per information from the missile guidance officer, Capt. Muminovic, the basic parameters of the target engagement. The shift clerk also wrote the facts into the battalion combat logbook. Lt. Col. Anicic also, as the battalion XO, organized the march to the new location. The hard work soon took the toll onto the battalion men.

Every missile crew after the successful hit and downing of the enemy airplane celebrate. That was the same situation that night in 3rd battalion. This was the first target downed on the Serbian territory. However, the time was crucial, and the battalion needed to be relocated as soon as possible because there was realistic danger that the position has been compromised and it may follow with the air strikes. The brigade command issues an order at 21:15 to relocate the unit onto the new position and the battalion moved to another position in about 2 hours.

TV station, Studio B, at 22:00 informed that “F-117A, proud of US Air Force has been downed into the Srem mud”. That was the blast which created the shockwaves through the media, military and aviation circles. Jubilant soldiers and civilians from the neighbourhood areas of the crash site poured to see the wreck. Hardly any media in the world didn’t report about this. Ken Dwelle was the name on the F-117A canopy. Most media reported that name as the pilot of

the airplane, which was actually wrong (**Figure 8-24**).

What happened after within the battalion, how it affected the course of war and all speculations will be explained in the following sections.

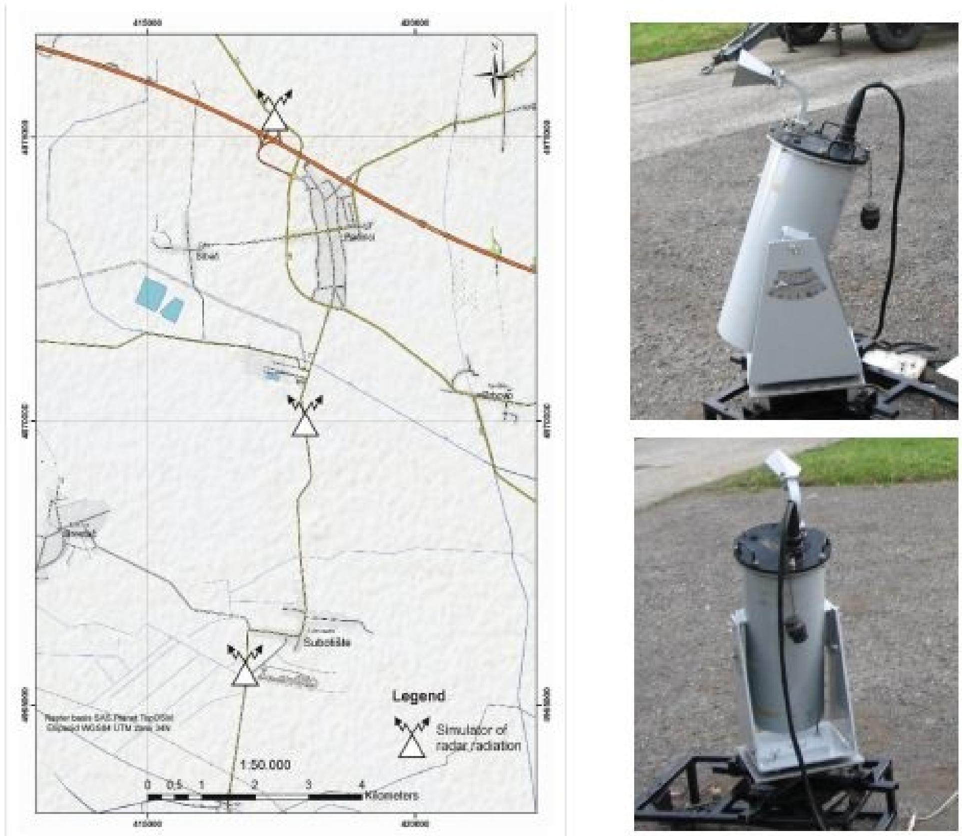


Figure 8-14: Position of radar imitator emission on the March 27 afternoon (left) and radar emission imitator right. (Source: authors)

Figure 8-15: Lt. Col Dani and lt. Col. Anicic (Source: C. Ljubinkovic)

Figure 8-18: Crew that downed the Stealth:
Standing left to right: Sgt. Dejan Tiosavljevic, Sgt Dragan Matic, Lt. Col. Zoltan Dani, Lt Col. Djordje Anicic, Maj. Boris Stoimenov
Kneeling left to right: Sub. lt. Darko Nikolic, Sgt. Djordje Maletic, Capt. Senad Muminovic, Sgt. Vladimir Ljubenkovic
(Source: book "Smena" (The Shift))

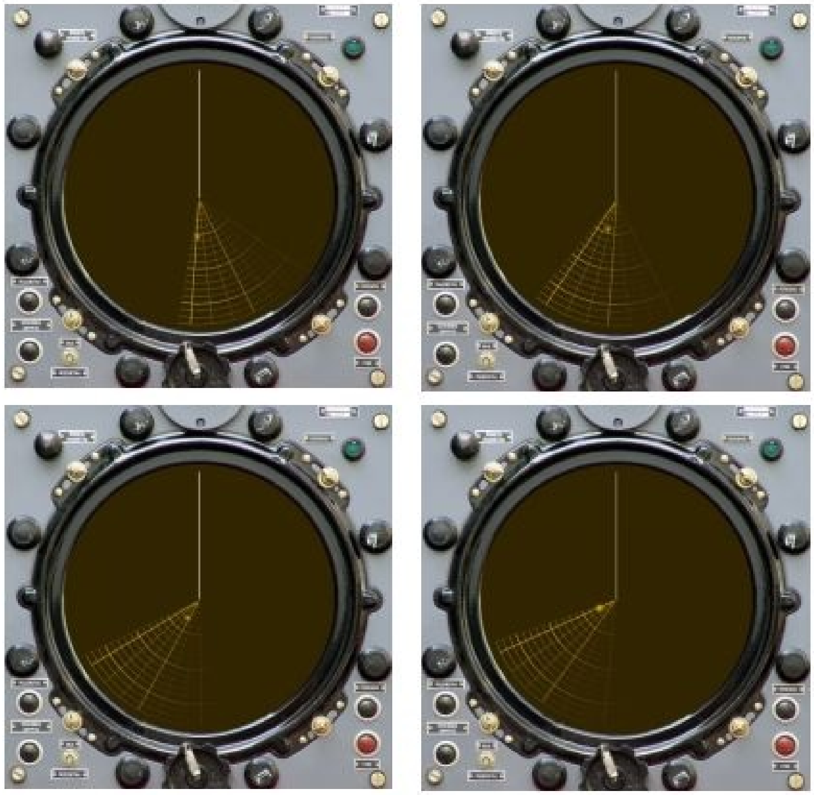


Figure 8-16: P-18 radar illustrations (left to right and top o bottom):
Left top: Lt. Col Anicic observed the approaching target
Right top: target at azimuth 195; Bottom left: target at azimuth 210 first search;
Bottom right: target at azimuth 230 second search. (Source: authors)


Figure 8-17: Sgt. Matic at his combat position on F2. (Source: authors)

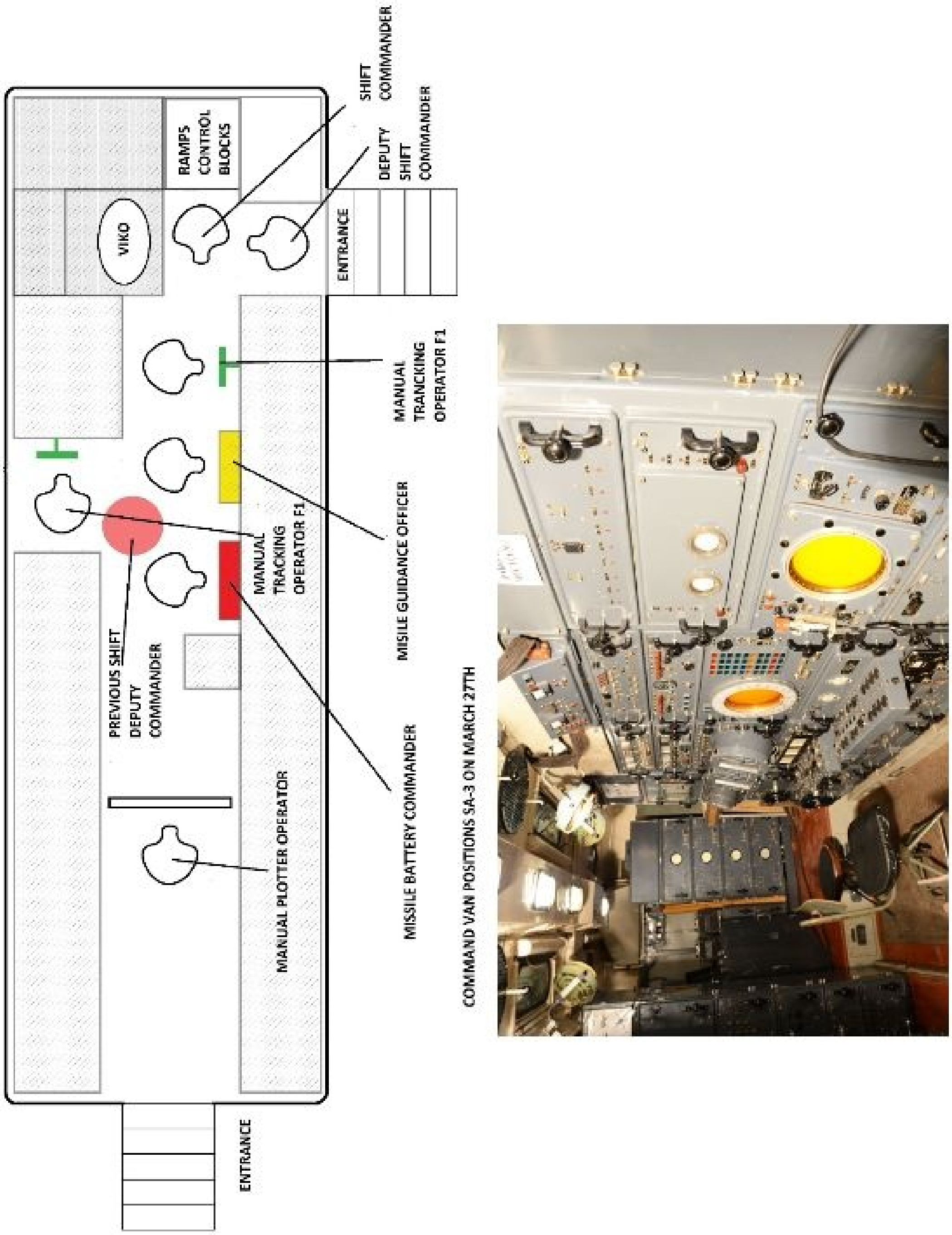


Figure 8-19: UNK layout with the crew positions on the march 27 during the stealth engagement (left) and combat stations(right)
(Source: authors)

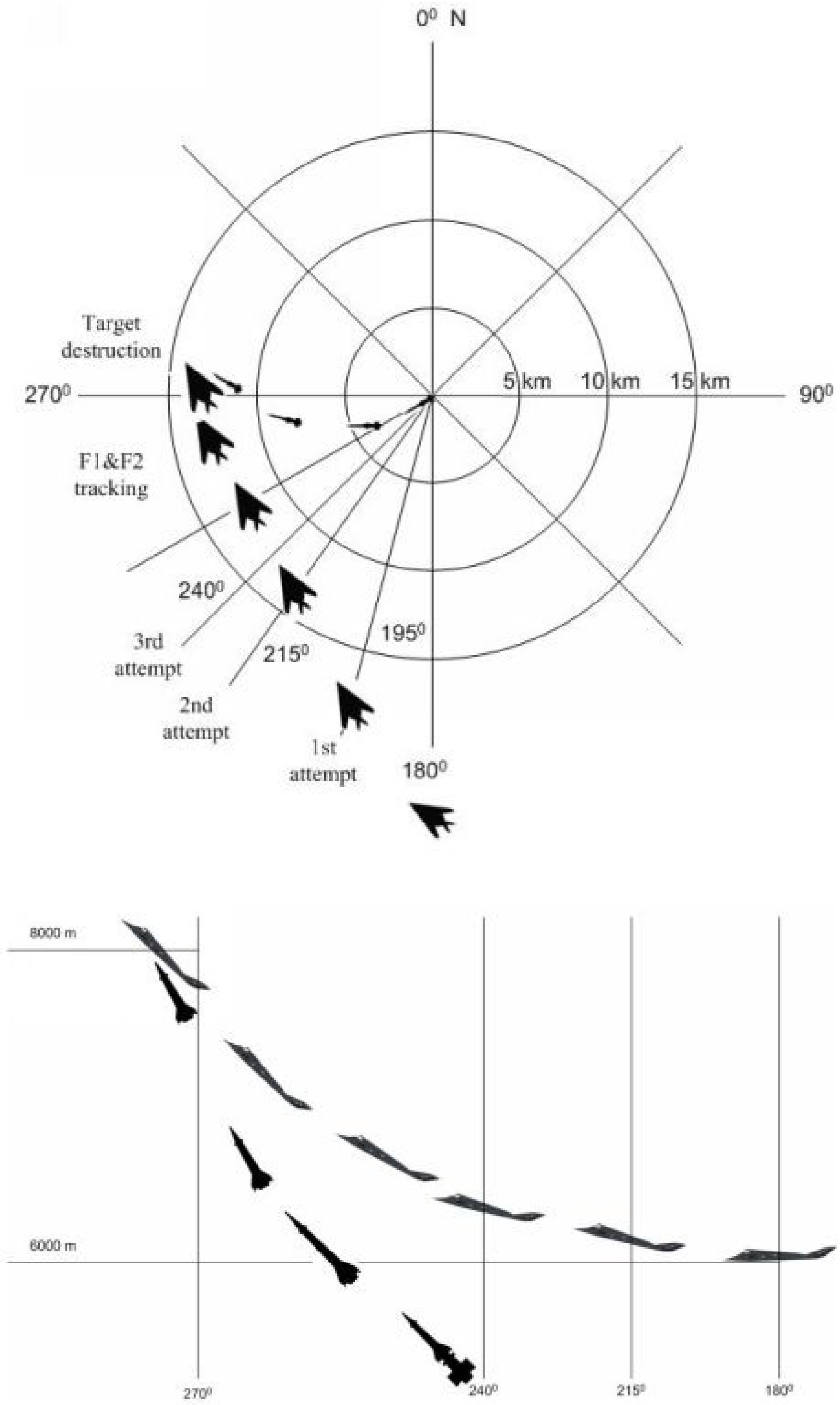


Figure 8-20: Diagram of F-117A engagement. (Source: authors)

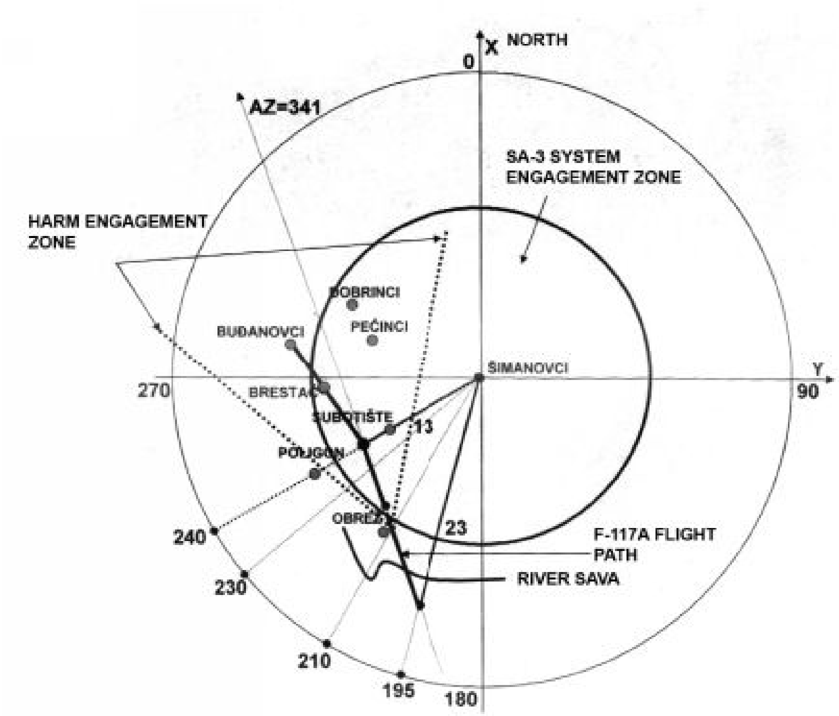


Figure 8-21: parametric analyze of the F-117A engagement (Source:B. Neskovic)

Figure 8-22: F-117A immediately after the first (and only) missile hit
(Source: Osprey Publishing, Air Vanguard 16)

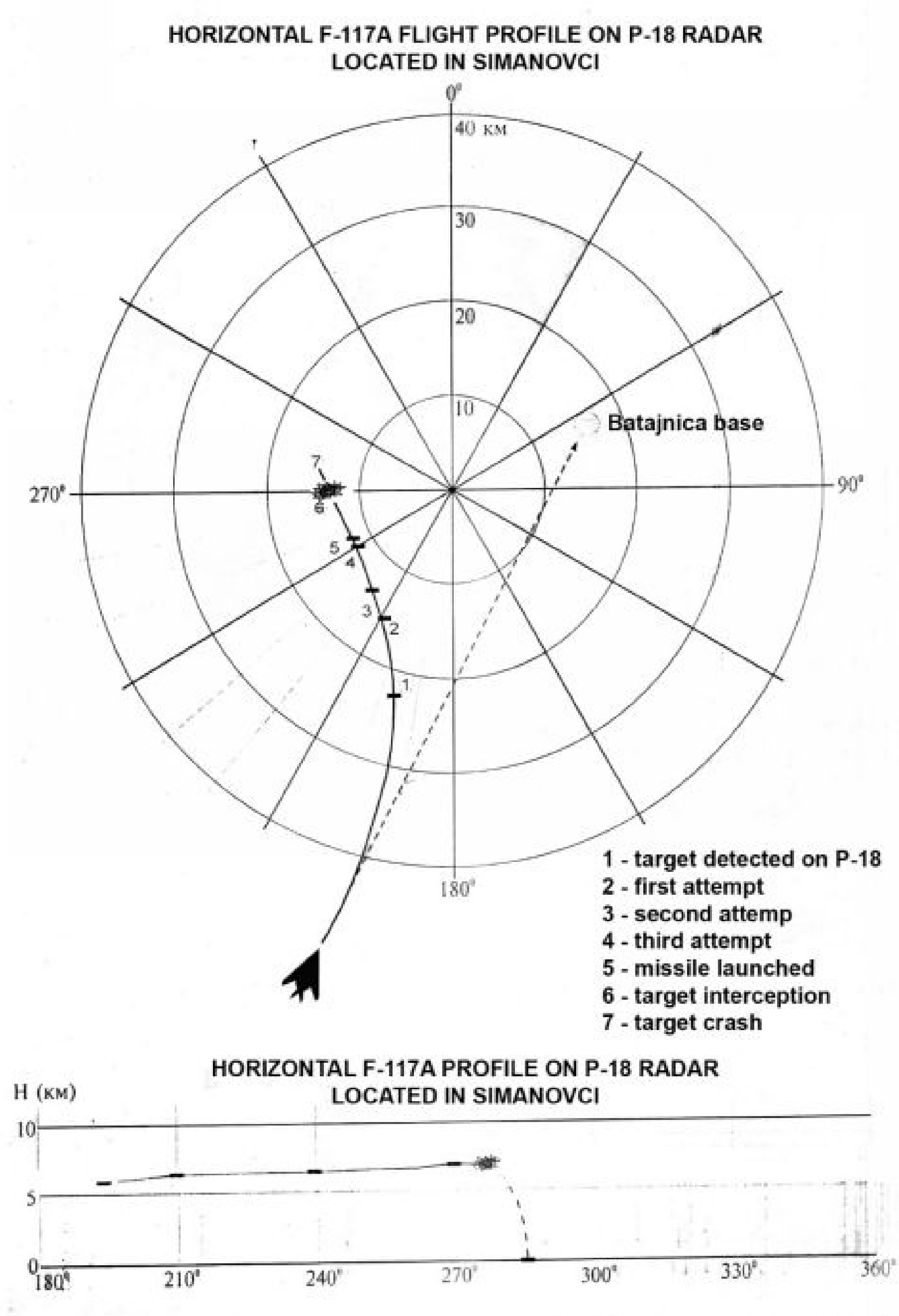
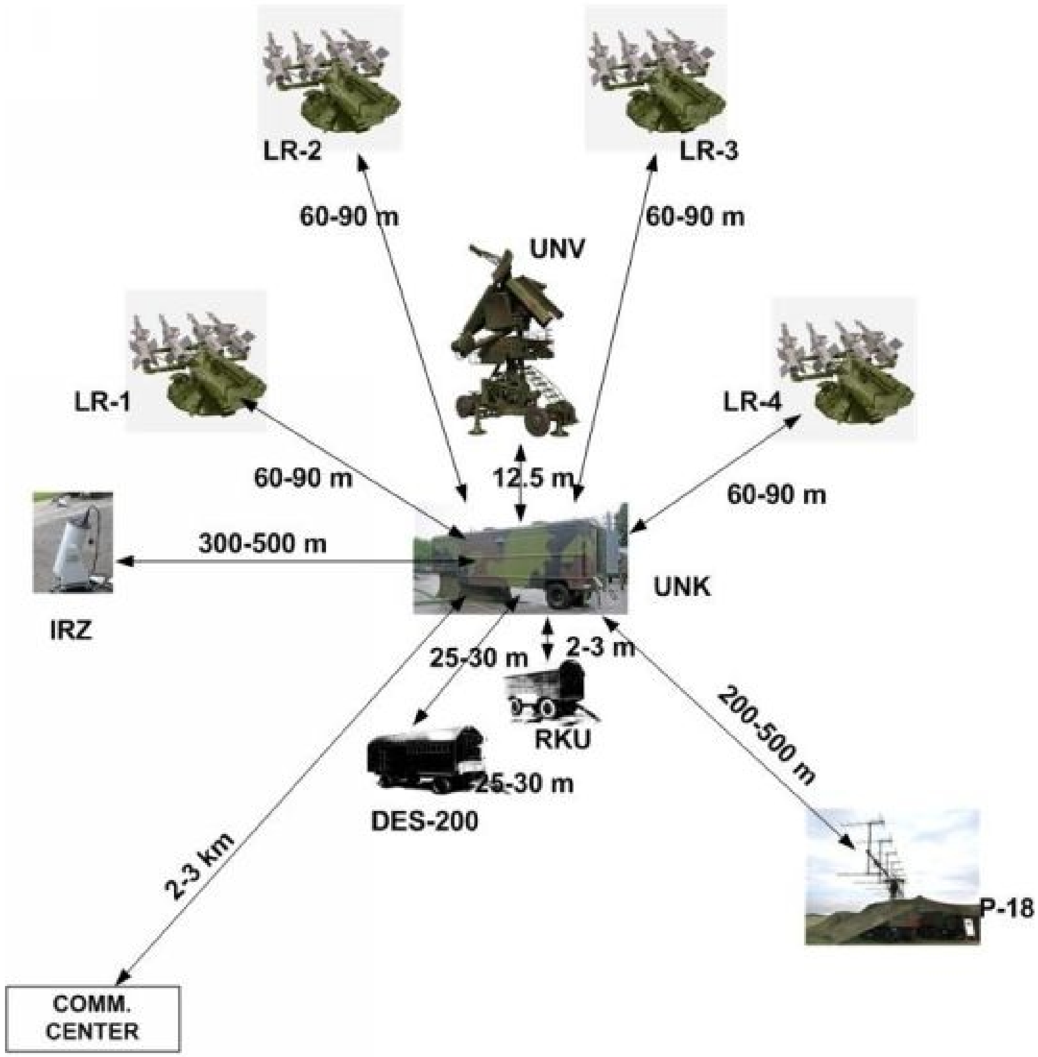


Figure 8-23: Horizontal and vertical flight profiles on P-18 radar located in Simanovci (Source: B. Neskovic)

Figure 8-24: F-117A wreckage near the village Budjanovci
Fuselage (top picture) and wing (bottom picture)
(Source: RTS)

Figure 8-25: ARRENA combat simulation training van. (Source: authors)

Figure 8-26: 3rd battalion UNK missile guidance station (van). (Source: authors)



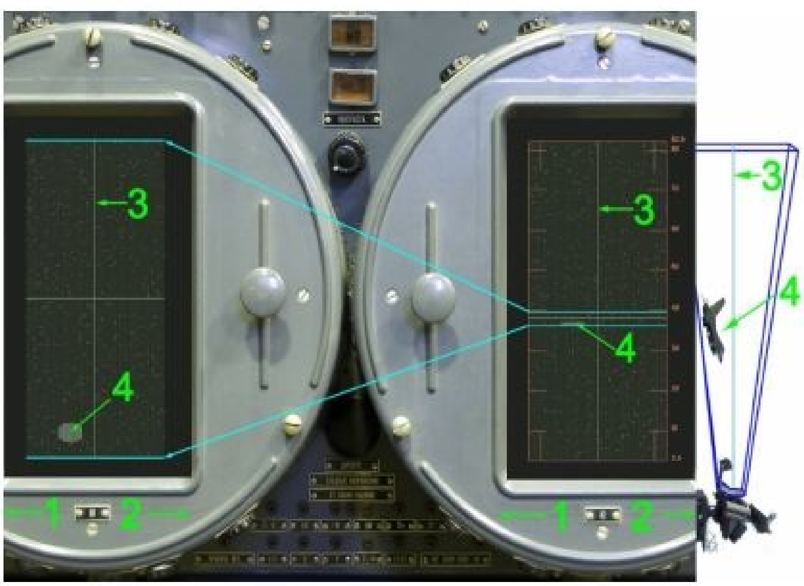
LR – LAUNCHER
UNK – COMMAND VAN - GUIDANCE STATION
UNV – LOW BLOW RADAR
RKU – POWER SUPPLY DISTRIBUTION VAN
DES (5E96) - POWER SUPPLY UNIT
P-18 – SURVEILLANCE RADAR
IRZ – RADAR IMITATOR
COMM. – COMMUNICATION

Figure 8-27: Typical 3rd battalion combat position. In Soviet procedures, UNV can located up to 75 m from UNK. The 3rd battalion allowed only 12.5 m maximum because the lack of cables. Often UNV was positioned right beside UNK. (Source: authors)

Figure 8-30: Battery commander screen.
(Source: authors)

Figure 8-28:VIKO radar screen in UNK station. View form the deputy shift commander position (Source: authors)

Figure 8-29: Battery commander station (left) and command table (bottom). (Source: authors)



1 - Direction down
2 - Direction up
3 - Boreseight
4 - Target under boresignt

Figure 8-32: Indication of the target position on the missile guidance position. (Source: SAM simulator - authors modification)

Figure 8-31 (left): Missile guidance officer station. turning two wheels (bottom of the picture) he can search for the target as per orders from the battery commander. Once when the target is acquired he can transfer to the manual tracking stations and launch the missiles. (Source: authors)

Figure 8-33: Manual tracking on F1 screen. (Source: authors)

Figure 8-35: F2 screen - target is the dot at the top and the missile approaching the target is blimp just below the target. Few seconds until interception. (Source: authors)

Figure 8-34: Manual tracking operator on F2 station. At the top is the TV screen for visual tracking in passive mode. (Source: authors)

Figure 8-36 (right): UNV antennas (Source: authors)

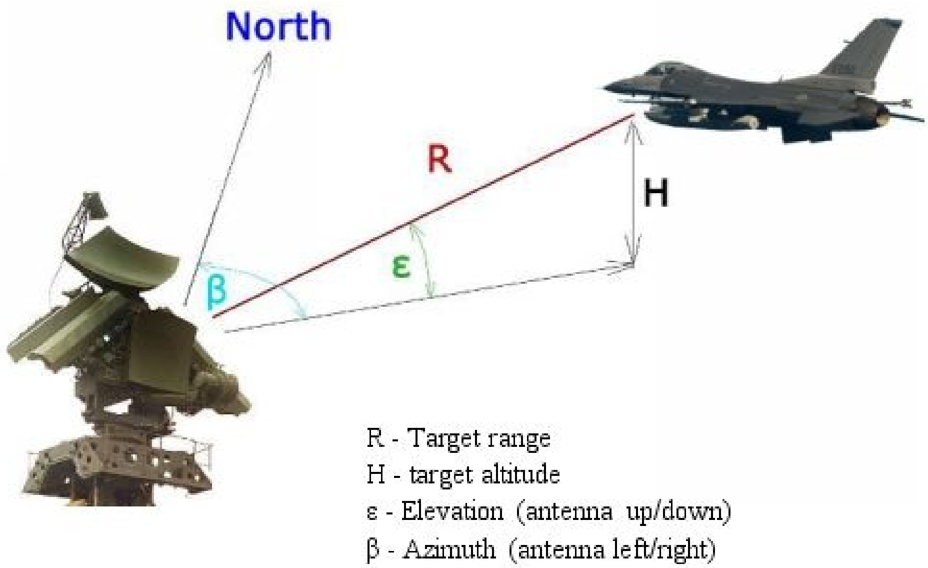


Figure 8-37: Parametric coordinate system.
(Source: SAM simulator – authors)

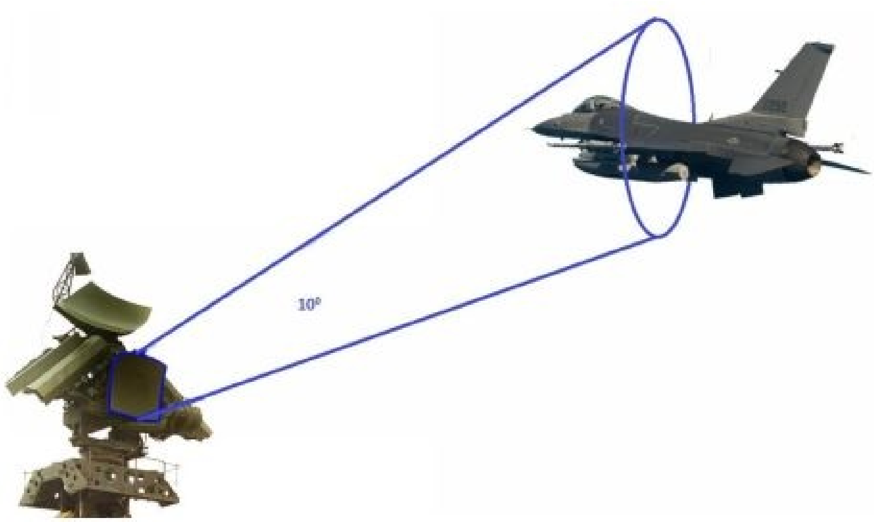


Figure 8-38: SNR-125M1 target acquisition through UNV. (Source: SAM simulator - authorsmodification)

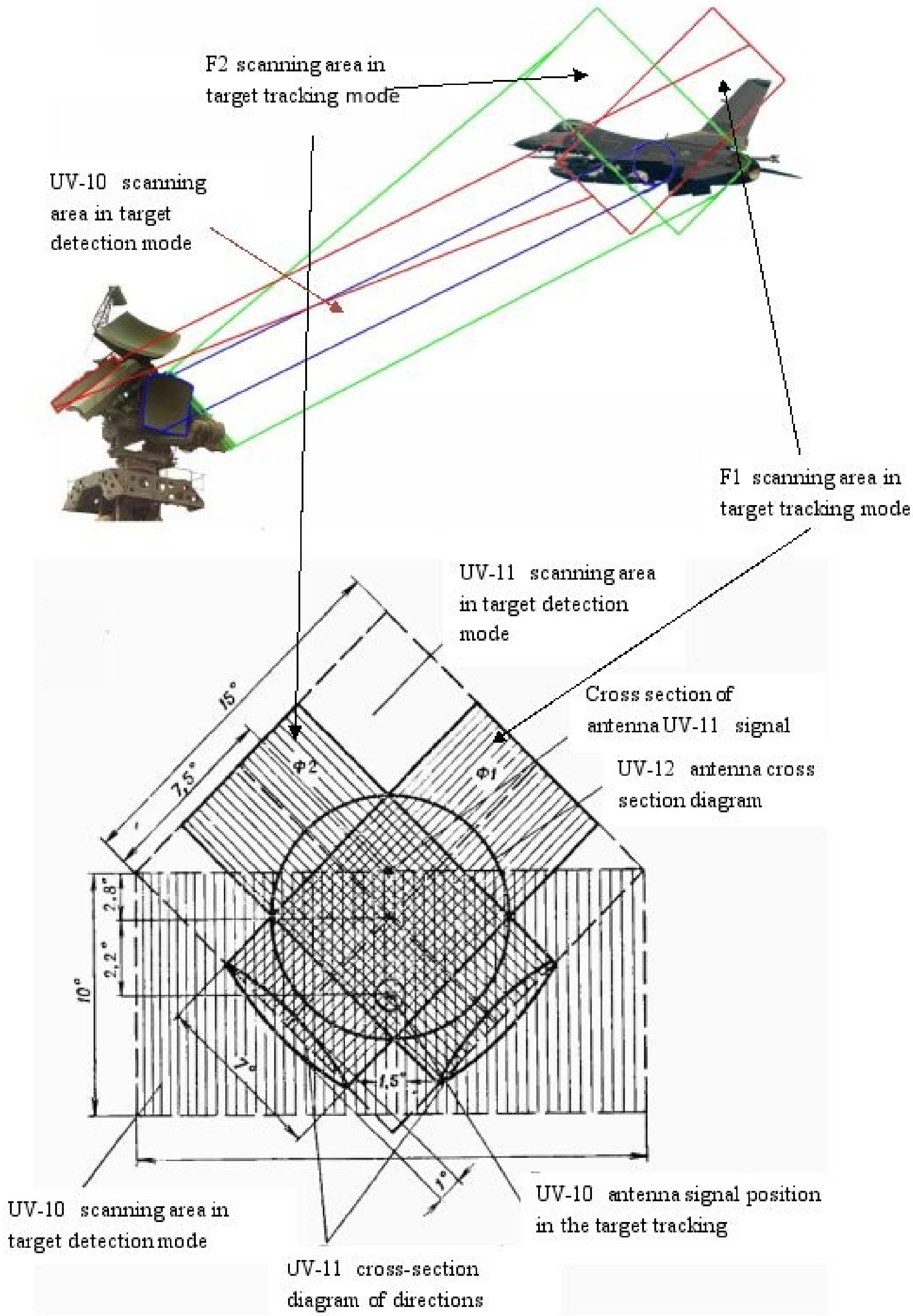


Figure 8-39: UNV antenna emissions zones top (Source: SAM simulator) and zone interlocking diagram (Source: Soviet S-125M manual)

Vega 31

Vega-Three-One or Lt. Col. Dale Zelko (**Figure 8-40**), at the time of engagement, was one of the most experienced combat pilots with operation Desert Storm under his belt. He was the member of the 8th squadron deployed during the third week of February 1999 from Holloman AFB, New Mexico to Aviano Air Base in north-eastern Italy in a demanding nonstop 14 hour and 45 minutes flight. It was the longest flight that he has ever flown. The most challenging part of that deployment sortie for him and majority of other pilots including the squadron commander, Lt. Col. Waltering, were over the Atlantic Ocean at night-time flight. It was pitch black and hard to find a horizon line. Lt. Col. Zelko has never fought so hard against spatial disorientation before. And the F-117A's cockpit is really very susceptible to spatial disorientation; it's a constant challenge not to get sucked into it. It was mentally and physically exhausting. Dressed in his rubber "over-the-water" flying suit, among pilots called "poopie suits", pilot is restricted to do "physiological needs".

This chapter includes Col. Zelko own words as he told in the interview to the Brasilian National Air Force Magazine journalist Carlos Lorch with the authors inputs.

For US pilots, operation Allied Force was a different story than operation Desert Storm as per their own stories. The dynamics of the politics involved created many constraints, which prevented pilots from employing optimum tactics. Lt. Col. Zelko also felt that at the beginning of Allied Force there was an overall element of complacency in their attitude of seriousness.

During the month or so that 8th squadron were there getting ready for operations, most of the pilots were really concerned about how they were planning on going into operations. The whole scenario was very confusing at first, the reason being, there were a lot of different operations going on directed by a variety of entities, such as NATO and the UN, and when they first started flying combat missions they still hadn't developed appropriate special instructions, having to rely on those being used by what were essentially peace keeping forces. On those first few nights of the war, the pilots were briefed and told that if they went down, and captured, they were to claim that they were not enemy combatants! The authors didn't confirm this in conversation with the

pilots but knowing how military bureaucracy works, it is quite possible that the pilots got this "instructions". This, of course, was ridiculous. All of that changed dramatically, immediately after the Vega 31 episode. The F-117A, serial number AF 82-0806, downing and Combat Search and Rescue (CSAR) was a much-needed wake up call. In Yugoslavia, pilots did not go in there and pound Serbian Air Defence. They essentially left it untouched or barely scratched at the beginning, which was significant. There’s a large difference, even for a low observable platform, if the one is going in against a crippled air defence compared to full-up very capable system. Personal experience with the triple-A was not nearly what Lt. Col. Zelko experienced during Desert Storm, but certainly the threat from the SAM systems, combined with the factors hindering pilots from operating in an optimum tactical way, as well as other elements, all came together opening the way for the shoot down.

For combat sorties over Yugoslavia, the theatre of operation has been divided up into a northern and southern sector (44th parallel). If the task were going after targets in the north of the country, then the airplanes would fly out of Aviano across Slovenia, rendezvous with refuelling tankers over Hungary, wait for push time, and stealth up, drop off the tankers and away on to strike missions. There were either one or two targets depending on the target itself and on what kind of weapons were carrying.

Traditionally, F-117A weapons load consisted of two 2,000 lb smart bombs. If the targets were in the south, airplanes would fly down the Adriatic, refuel off the tankers maybe 2/3 of the way down, push through Montenegro, and go in that way (**Figure 8-41**).

Lt. Col. Zelko flew on the first wave March 24, the first night of Allied Force. He flew again on the third night and then he flew on the fourth night. The main objective on night of 27 March was a critical, heavily defended target in and around Belgrade. That was underground command center Strazevica (**Figure 8-42**). According to his statement, he knew what he was up against. In majority US articles, the opinion of Serbian air-defence was that:

> *“Serbia was defended by a superior IADS encompassing state of the art Russian equipment, and manned by highly trained, skilled and extremely motivated operators”.*

The last portion of the sentence about the people is true, but “most-modern

state-of-the art Russian equipment" is very far from the reality. Serbia was defended by outdated but still, if applied correctly, effective air defence systems. Stating that the opponent is technically sophisticated rise the role and achievements of own air force. One of the high-ranking US commanders compared the Serbian air defence with the car - it is like a old car, with a lot of mileage, but still running well, even it is in a need for a major overhaul.

The Vega-31 target for the night had actually been on the planning board, and flown against before, unsuccessfully. So, there was another attempt on the fourth night, to neutralize the center. Some missions for the night of March 27 were cancelled because of the weather conditions. It was decided that the attacks will be spearheaded with F-117A and B-2. First wave consisted of eight F-117A, four F-16CG, two F-15C and eight F-16CJ for the SEAD mission. These aircraft were supported with one British E-3 Sentry (code name Magic 86), one EC-130E flying over Bosnian airspace, four EA-6B for radar and communication jamming and a group of KC-135 fuel tankers. The second wave consisted of 4 F-117A and reduced support aircraft and the third wave, three to four hours later on that night, with B-2 bombers flying directly from US base. It was a very challenging night, weather wise, and all other Allied Force strike packages had been cancelled. Only eight F-117's went out after targets in the northern part of the country.

During the early portion of ingress, Lt. Col. Zelko was monitoring a primary strike frequency, listening to other events unfolding that were part of the strike mission. Even before stepping to the aircraft from his squadron life support shop, he had had a deep feeling and sense that if any night was particularly suitable to his aircraft being shot down, that this was it. He was well aware of his vulnerabilities, the risks and dangers of that mission that night. As he later said:

> *"The information coming over the radio during ingress, simply increased my gut feeling that something bad was very likely to happen that night. So when it happened it didn't surprise me at all. As a matter of fact, I watched it happen!"*

What is surprising is that neither Lt. Col. Zelko nor any other pilot spoke about the Radar Warning Receiver (RWR) tone which is a common feature in all airplanes. On the question did he ever hear that his answer was that:

> *"That gets into capabilities of the F-117. But I will tell you that I*

visually watched the surface to air missile engagement, and that even in its early stages there was no doubt in my mind that they had me. I did everything I could to prevent it but it was just unavoidable. And remember, I had a front row seat throughout the entire engagement. So was it pilot related? No. Was it maintenance related? No. Was it a good shot? Yes, it was a good shot. I can't get into details about exactly how they were able to put a surface to air missile warhead into the same airspace as an F-117 low-observable aircraft because that's very sensitive, even today. But I can kind of give you a sense. You know it's not invisible technology. We have never said it was invisible technology, we've always said it was low-observable technology. The F-117 relies a great deal on its low-observable characteristics to survive.

So, just like anything, there are limitations and vulnerabilities. And if you give an adversary the opportunity to exploit them, they will. The Serbs are great fighters and they certainly saw the opportunity. So essentially, we gave them the opportunity because of the way we were operating. They saw the opening, they took advantage of it, and it was just a good shot. Was it preventable by us if we had changed things? Yes, absolutely."

However, in the book "Stealth Down" by Ross Simpson, there is a paragraph on page 102 which says:

"He was in the process of clearing the target when heard a sound that sent a cold chill up his spine. A warbling sound from the radar warning receiver told Sugar D (Zelko's flight name) he was being targeted by surface-to-air missile, most likely Soviet built SA-3. Moments later, the SAM left its launcher in a blinding flash and headed toward him at more than twice speed of sound"

It is obvious that there are two different stories. To support the theory that Ross Simpson mentioned, Serbian missile operators recorded that when they started tracking the target with the fire control radar, the target started to manoeuvre. That was in the second attempt, before the missiles were launched.

More information about the RWR on F-117A can be found in the following section "Mystery of RWR receiver".

Now back to Zelko. On his own words, the pilot saw two missiles; however,

he was not sure if there may have been others. He started tracking them visually right after launch. During this he rapidly started to climb from initial height of 6000 m. This manoeuvre is not typical SAM evasion tactics. The usual defence is to employ a hard breaking and turning manoeuvre while deploying flares and chaffs. The goal of the hard brake and turn is to get outside of the cone in front of the missile in which it can obtain and keep a lock and flares and chaff possibly insert some dirt or other confusing heat or radar signature between the plane and the missile. Fighter airplane will dive toward the missile than suddenly change direction thus while imposing high “G” manoeuvre on his airplane, it will make the missile to “lose” the contact. F-117A is not manoeuvrable airplane if compared with other fighters such as F-16 or F-15 thus once “locked” there is very small chance that it can evade the missile.

> *I thought to myself, matter-of-factly: “You know what? This is bad. I don’t think I’m going to skinny through this one.” I had been shot at many times before, but that was the first time I’d ever felt so strongly that I wouldn’t make it due to SAM technology.*
>
> *The first missile went right over the top of me. So close, actually, that I was surprised it didn’t proximity fuse on me. I could feel the shock wave of it buffeting the aircraft. As soon as it went over I quickly re-acquired the second missile visually and when I did, I thought: “It’s going’ to run right into me.” And it sure felt like it did.*

The proximity fuse activated the warhead close to F-117A left wing. The impact was very violent and slammed the airplane into left roll with negative “G”. The impact was visible as far as from the refuelling KC-135 tanker over Bosnia.

There is a discrepancy how many missiles pilot saw. The battalion fired 2 missiles and the second one lost the target tracking channel K2 right after the launch and continues flight on the ballistic trajectory. Only first one acquired the target. The pilot claims that one near miss him and the other hit him. There is also no other unit which fired upon him. Is it possible that in the “heat” of battle he simply exaggerates? Probably yes.

The pilot F-117A sits in an ACES II ejection seat. Pulling the ejection handles retracts the shoulder harness and lock the inertia reel, fires initiators for canopy jettison, and ignites the rocket that remove the canopy. After the canopy

separated from the cockpit, lanyards fired two seat ejection initiators which ignited a rocket that catapulted pilot on the ejection seat out of the cockpit. The ejection sequence takes only 1.4 seconds from the moment the rocket motors beneath the seat fire until the pilot separates from the ejection seat.

> *"Even though I strap in extremely tight, because of the way the G forces were acting on the plane and ejection seat, my body was sliding out from underneath the lap belt. Normally, I like to sit with the ejection seat all the way up in order to better look outside the cockpit, so the clearance between the top of my helmet and the canopy is pretty small to start with. So I was pinned to the top of the shoulder straps, with my butt way out of the seat and my torso doubled over in the worst possible position for an ejection. I was immobilized in this awkward position by the 7 negative G force of the tumbling plane, trying to get my hands down to the side ejection handles. Despite the violence of the event, mentally and emotionally it was all very calm for me. I figured the only thing I could do was to push isometrically with my head against the top of the canopy which would perhaps straighten my spine somewhat once the canopy blew, and before the seat went up the rails. And I tried that move, almost like a wrestler who's pinned down on his back trying the bridge manoeuvre. I don't know if it had any effect. It was amazing to many that I survived at all.*
>
> *I remember every fragment of the entire strike mission; shoot down, ejection, and CSAR. All, that is, except one. There's just one slice of this entire affair that to this day I just can't get a hold of. I can't recall it as if it never happened. And that's actually reaching the ejection handles and pulling. I may have been unconscious which makes me know even more strongly that I had some help from Heaven getting to those handles and pulling. And in that body position I probably barely got a fingertip in those handles. The next thing I remember is I'm in the seat out of the aircraft. I can see the cockpit falling away from me and I don't recall the 18g kick in the butt. I don't recall going up the ejection seat rails, none of that. As I was tumbling through the air, myriad thoughts went through my mind, all in a casual, light humorous sort of way. I even remember seeing a mental imagine of myself kicking the dirt with one foot saying: "Nuts, isn't this inconvenient. My Mom's not going to be happy with me and I might not be able to call my daughter tomorrow on her birthday", who would be turning ten. The good news is that I was able to call her.*

Another thought that came to my mind had me imagining standing next to the Serbian SAM operator, enjoying a light conversation and congratulating him.[*] *"Real nice shot!" Then I remember saying to him, "But you're not going to get me!" Not in an arrogant or cocky way, but with a surge of determination flooding my mind. I realized immediately how important it was to deny the adversary the exploitation and propaganda potential of having a captured senior officer F-117 pilot. This remained a powerful source of determination for me. I estimate I was between 8 and nine thousand feet when I first got under canopy. It was 19:40 Zulu, 20:40 local time*[*]*. From pulling the handles to a fully inflated parachute it takes 1.4 seconds. To me it seemed like hours. I instantly went from this extreme violence and chaos to absolute calm when the canopy inflated. All I could hear was a gentle swishing sound of the seat kit and life raft hanging below me on its 25-foot lanyard as the canopy went through its normal oscillation. So I looked down and quickly started getting oriented. Looking north, the first thing I could see was Belgrade off to my right.*

[*]The second meeting between the pilot and missile battalion commander indeed happened after 12 years, when Col. Zelko visited Serbia and finally met in person the man who was one of the crew commanders that shot him down.

[**]The reader can notice that there is a 2 minute difference between the battalion timing and the time that pilot remember.

And then underneath me, slightly south/southwest, I could see two little fires burning and I figured that was the aircraft. I looked down and saw the seat kit and life raft; I didn't even think to specifically check for injuries. The first time I realized I had an injury was about an hour and a half after ejection at my hole up site on the ground. The next thing I did was check my equipment. I still had my mask on so I disconnected it and tossed it away. My helmet was still on but the visor was gone. Then I looked up and checked the canopy, which I could see clearly in the nearly full moon night: "Perfect, no Mae West, no line-over's, no blown panels, no streamer..." and it was then that I noticed it. "You have got to be kidding me," I remember thinking to myself, still in a light humorous way, "an orange and white panel parachute!" It was glowing like a Chinese lantern. I patted one of my survival vest pockets with the signal flares and jokingly considered lighting one up to help the Serbians spot me even more easily! Of course that's not what I did. In fact, I knew that despite the presence of a large number of air

breathing and non-air breathing NATO assets out there, there could still be a chance that nobody was aware of what just happened. I felt it vitally important to make good two way contact with a friendly as fast as possible. I reached into my g-suit pocket and took out my personal mini-maglite flashlight, which was fitted with a red lens cap. I was familiar with the settings on the top of the survival radio but I wanted to be absolutely sure I had the correct one selected when I started transmitting. I had SAR frequencies, or I could go to 243.0, which was the guard frequency. I could also activate the emergency locator beacon. I knew where all the settings were but I wanted no uncertainty. Funny, I was already transitioning my thinking and frame of reference from "pilot-in-cozy-cockpit", to the attitude and actions of a high-speed special operations, special tactics covert and low-profile guy on the ground. So in order to prevent anyone seeing the tiny light from my flashlight, floating thousands of feet above the ground, I tucked my body around the light as best I could while I did a quick visual confirmation of the radio settings.

According to the procedures, when the pilot is forced to eject he was adamantly not supposed to do anything other than to take basic care of himself right after the ejection, thus meaning not to try to establish the radio contact. Maybe start to treat for shock or get a little orientation. The pilot should wait until get on the ground, settle down, find an initial hold up site, treat oneself for shock and injuries, only then try to initiate radio contact. Lt. Col. Zelko has different reasoning as he felt great physically and mentally with a very high state of situational awareness. As a life-long fitness "fanatic", he was physically very well prepared, maybe the best in the whole squadron. The first reason was that he had a basic radio with no secure voice and no over-the-horizon capability. He knew that the best chance to get two-way contact was at altitude. He also felt it very likely that he could be quickly captured after hitting the ground with no chance to get on the radio. What he wanted is to deny Yugoslavia the huge exploitation potential of having an alive-and-well F-117A pilot and rescue forces coming after him having no knowledge of his status. And overall, he sensed how crucial it was to get things going - to get the CSAR energized as fast as possible in order to have the best chance to deny the Serbian forces what he knew would be the ultimate prize in this whole episode: the F-117 pilot. So he started making his mayday calls, maintaining the best possible radio discipline. He realized how important it was to inhibit the adversary the ability to fix his position. There was no secure voice going on here so he assumed the Serbs were listening to everything, and he assumed the whole time they knew where every player was

and what it was doing. After some time, he finally raised Frank 36, a KC-135 tanker refueling F-16s over Bosnia.

The information Zelko passed to KC-135 was that his last known position in the aircraft was his point after target. So that gave them a rough idea of where he might be. Once he was satisfied he had made good two-way contact, he tucked the radio away and got busy with other things. All the while he was on the radio, he tried to orient himself. He was coming down through layers of clouds. When he was out of the clouds he could see pieces of ground. As a backup he checked the magnetic compass which was in his survival vest pocket.

The estimate was he broke through the bottom layer of clouds somewhere around 610 m (2,000 feet), giving him roughly two minutes remaining under canopy to better orient and make some initial plans and decisions. As soon as he was underneath the bottom layer of clouds he pulled the four-line jettison, giving him the ability to steer and some command over where he was drifting.

The first thing he saw was a town (Ruma) about 5.5 km (3.5 miles) to the north. This was connected to another town about 2.5 km (1.5 miles) behind him by a two-lane road, running roughly north-south. There was quite a bit of traffic on the road. He was drifting north/northeast. As far as he could see the terrain was open, flat sections of farm fields separated by sparse shrub lines or irrigation ditches; not ideal for cover and concealment. There was also a major four-lane highway to the north of his position running northwest to southeast (Belgrade - Zagreb highway).

With some aggressive steering he was able to crab into the wind and land successfully on an open ploughed farm field some 40 m west of the road he had seen, next to what seemed at the time to be a "T" intersection that led off to the east. Although he landed softly, there was a stiff wind, so he was drugged a little bit. He was able to deflate the parachute canopy than stayed still for about a minute.

Before he touched down he picked out a spot just west of the road some 250 m away, where he hoped to be able to use as an initial hold up site. he thought it was a drainage or irrigation ditch. He got busy securing landing area and first pulled in parachute, then took off helmet and harness as well as any “hardware” items that could catch some light and give position away. He wanted to get away from that landing spot as fast as possible and travel small and light. So he put all

of this stuff in the bottom of a ploughed furrow and then put dark green one-man life raft on top of that. He packed dirt around the edges and on top of the raft so that the wind wouldn't flip it over and expose everything. He was very cautious to minimize disturbing the top of the furrows. That would give easier to spot from the road, particularly being illuminated by the near-full moon. As he moved towards chosen initial hold up spot he was careful to step only in the bottom of the furrows so that it wouldn't disturb the neatly groomed surface and give away direction of travel. One of the first things he did in hold up site was to grab some of moist dark Serbian soil and do a bit of expedient combat camouflage to cover all the exposed skin and soften the glow of face and neck. An hour later he took off gloves to reapply "soil camouflage" to wrists and hands. This is when he noticed that the back of the right hand was caked in blood from the scratch he got during the ejection.

In that part of Serbia it was a wet and cold night. The pilot dress was to egress and he had on four layers of clothes, with the top layer being winter flight jacket, as well as three pairs of socks - two thin- cotton and one high-quality thin wool ski sock. This provided fairly comfortable conditions throughout the night. Important thing was that he was extremely well hydrated before ejecting and had brought along at least 12 extra flex packs of water besides the 12 normally placed in the survival kit by the life support professionals in Aviano. Water is so vital, helping to reduce potential shock; it raises levels of alertness and provides overall strength and endurance to the body and senses. Good dinner before the flight provided long-term complex carbohydrate energy. Almost like a marathon runner carbo-loading before a race. He also had four power bars in the pocket. But not everything can really prepare downed pilot for every circumstance.

The pilots are trained in the survival courses to meticulously assess and adapt to the situation. As soon as he was in the hole he made a quick check of all the equipment he had: a survival vest, seat kit and a hit-and-run pack. The seat kit is kind of like a little backpack containing survival/evasion equipment. If the one land and don't have time or the means to take much, he can sling the hit-and-run pack over the shoulder and take off. It has the most essential items of equipment the one may need to survive and evade and is shaped almost like a banana pack.

Within the first hour after he had landed, still holed up in the shallow irrigation ditch, Zelko detected and began monitoring Yugoslav search activity very close to where he was. Yugoslavs knew that they had shot down an aircraft and were at the wreckage site extremely quickly, probably within 15 minutes of

the crash. They certainly realised that they had shot down an F-117A right on the spot. The next obvious conclusion was that they would do whatever it took to capture the pilot. So they unleashed a "giant" manhunt which involved military, police, and villagers in the area. The latest gathered with the hunting guns and dogs and the police was actually tasked to “restrict” their action because there was a danger that if the rescue team is encountered it will lead to heavy fight and possible casualties. The question was how the pilot will be treated if captured by local hunters. Hard to answer, but definitely it would not be pleasant experience and "Genève convention" treatment.

> *I also experienced a little bit of the receiving end of our own actions when I was in my hold up site. At first I didn’t quite know what it was, but remembering the Air Tasking Order, I quickly realized it was the B-2s that were to bomb targets in the general Belgrade area after us. Although a safe distance away, the bombs hit close enough that the compression and shock waves that went through the air over me in my hole up site was significant - it got my attention. I later learned and appreciated what those guys did as they actually flexed some of the targets which they thought would be close to the rough area I may have been.*

What pilot described was that in his hole he felt the shockwaves form the bombs dropped from B-2’s, which flew after him. This is highly unlikely because all missions were cancelled after the command in Vicenza realised that one of F-117 is down. Even if the bombs had been dropped, his position was far-far away from the potential targets near Belgrade.

> *All through the night, I was trying to stick as close as possible to my pre-planned EPA, or Evasion Plan of Action. Of course, war fighting is fluid; it’s moment by moment, routinely demanding flexibility and improvisation. One dilemma for an evader is how to be as predictable as possible for rescue forces and as unpredictable as possible for the adversary. As soon as I was relatively comfortable with my state of concealment, I took out my hand held GPS. Shortly before we deployed to Aviano, our squadron life support shop had bought, with our own squadron money, a series of basic and inexpensive hand held GPS sets. It came in extremely handy that night.*
>
> *Before I turned it on, though, I made a rough guess of where I was. I had briefed extensively with our squadron Intel specialists, and familiarized*

myself with the area I'd be operating in before going into combat. I had a very good idea where I was. So I was facing north, and mentally visualized myself with my Intel folks in the squadron briefing room, standing in front of the Area of Responsibility - AOR - map. Before calling up the GPS, I guessed where I was in relationship to some predetermined references. Hunkered down, I couldn't raise enough satellites and had to expose myself somewhat to where I could hold out my arm and a portion of my body over the shallow curve of the ditch to get the best line of site with the horizon. I had my guess of my position and wanted to confirm it with what the GPS indicated, ensuring the machine was giving me accurate information. It was essential that I not pass bogus information to our rescue guys. The GPS data was right in the heart of the window of what I had rough-guessed! The first time I made voice contact on the ground was about one hour and twenty minutes into the event. I passed my position to one of our Command and Control assets. That was the first and only time I talked to him.

Still, and I didn't realize it then, even after my immediate contact under canopy and this initial contact on the ground, there was a great deal of confusion and uncertainty throughout the night, as to my location and authenticity.

The pilot minimized physical activity as much as possible. About three and a half hours into the event he detected what seemed like search dog activity south of his position, and shortly afterward he had a visitor - a sort of hunting size dog, walking along very deliberately and purposefully, seemingly looking for something. Suddenly, the dog stopped and looked interested in exactly where the pilot had been perhaps 18 m away. It was possible that the dog got pilot scent. The moon was now low on the western horizon and the pilot could see the dog clearly as he approached the hiding place, silhouetted against the illumination. The dog stood for sometime than turned and left.

All along, I had thought that if it was my fate to be captured, I'd rather be found by police or Serbian military, rather than by villagers who would likely be less charitable during capture. During the few minutes of my dog visit, not only did I hope to not have to tangle with the dog, I also imagined, still in a light humorous way, what would happen to me if I harmed that dog and ended up captured by villagers who owned it! I had a 9 mm pistol with me but of course I never considered using it because of the noise. To this day I don't know if it was military or police trained search dog, or perhaps

a villager's dog sent out to try and alert on something.

During the night a thick overcast low weather deck rolled in and some pretty heavy rain started to fall. The extreme darkness and poor weather made everything more difficult for the CSAR Task Force. However, it certainly worked against the Serbs as well. Although it added a significantly large extra challenge for the CSAR Team, in the end, the darkness, thick clouds and rain were probably more of a help than a hindrance, providing some much-needed cover and concealment.

The next time Zelko talked to anybody after initial contact on the ground, was a little over three hours into the event when the "Sandy" pilots arrived on scene (CSAR on – scene - commander). "Sandy" was the call sign introduced during the Vietnam war for the CSAR mission pilots and that name stuck to all US combat aircraft which fly CSAR missions. Zelko established and remained in radio contact with them for the whole rest of the event. Throughout the night there had been much uncertainty as to the pilot authenticity. Was he really Vega-31 or was this some sort of Serbian spoofing and laying an ambush?

From the beginning the operation wasn't really going smooth. There were many uncertain things. Throughout the entire evening numerous different sets of coordinates were produced from various sources indicating Vega-31's position. These were filtered down and approximately six actual sets of coordinates made their way throughout the evening to the "Sandys" and rescue helicopters. The helicopters had begun to execute and push in Serbia several times and were called off. So, there was repeated authentication throughout the entire evening, and the "Sandy's" were very skilful at managing that. Any aircrew member that can possibly be isolated behind enemy lines prepares some general and personal information about himself. This is kept closely-held and well-guarded, to be used only in the highly unlikely probability of needing to someday covertly authenticate. Authentication that night was effective and essential to the CSAR success (**Figure 8-45**).

The rescue helicopters faced their own problems. As the weather deteriorated, the visibility was poor and the lead helicopter in the final push into the Serbian airspace barely avoided the high voltage power lines. If the CSAR pilot didn't see the lines seconds before, it will result in the crash of one or more rescue helicopters thus ending the mission.

Helicopters were supported by sorties of A-10 airplanes which main task was to eliminate all ground threats. Not less than 10 airplanes were engaged. Proximity of Batajnica airport, the base of Serbian MiG squadrons, put an additional strain as F-15 fighter jets need to be in the area to cover the Serbian fighter treat and also F-16CJ with HARM missile for attack onto any detected Serbian SAM missile battery. Overall battle space was controlled by NATO Sentry airborne control center. There was no USAF AWACS in vicinity because they were engaged in the Middle East and Persian Gulf.

Pilots and aircraft crews reported that there were illuminated few times with Serbian engagement and fire control radars but this is highly unrealistic because simply the 3rd battalion who was in vicinity switched off all radars immediately after F-117A was shot down and started relocation. not even radar imitator was on. There were no available any low altitude surveillance radars such as “Giraffe”. The only illumination that airplanes may get was from far away P-15 radars. Serbian air defence was silent immediately after F-117A was shot. There is also no official records that SA-6 system radar was in operation at that time.

Thirty minutes before pickup the "Sandy’s" authenticated Zelko once again, because at that point they didn’t know if they were going to proceed with the mission, due to many factors, including deception, as well as their own contribution to confusion and uncertainty.

> *At that moment they asked of me the hardest thing I had to do that night: “Vega-31, is it alright to come in there?” As soon as I heard that I thought to myself: “Ahhh, don’t ask me that! Don’t make me take that decision!” Over a minute went by and I still couldn’t answer. Finally, one of the Sandy pilots came back on the radio, and this time he sounded just like a mom: “Now Vega- 31, if you don’t answer us, we’re going to have to come back and do this a little bit later.” Another 20 seconds went by until I finally said: “Ok. Go for it. Let’s do it!” The reason it was so gut wrenching to make that decision was that due to poor pre-Operation Allied Force CSAR information sharing, and no secure voice capability during the CSAR, I had essentially no true idea of the nature of who and also, due to being at ground level with no night vision capability, other than what God gave me, and short effective hearing range, I had limited awareness of precisely the extent and nature of surrounding enemy activity, or their capabilities.*

There were search forces within several hundred yards of me, and had been for most of the night. I could not confidently assess the risk of bringing those guys into what could develop into a very harmful situation for them. I just could not answer them. The reason I ultimately gave the go-ahead was that I felt fully confident my situational awareness was high enough that if capture was imminent, I'd be able to call off the CSAR and take care of a few essentials that I didn't want compromised. Even though the Sandy traditionally would have solid awareness of the objective area and be the one to make the continuous assessments and decisions, I still had rehearsed, throughout the night, a radio call I'd use, as well as the actions I'd take, for calling it all off. It was unexpected to be asked if it was ok to execute. When they were fifteen minutes out the Sandy's authenticated me again, reaffirmed if OK to come in, and told me to prepare my infrared strobe - my only covert signalling device. And again, I had a tough time answering.

It wasn't until this point that I first started to think; "You know, they may actually try something tonight." Up until then, although I never gave up hope or backed off my fierce determination, I was also a realist and did not expect a rescue attempt to be tried that night, if at all. I thought; "These guys would be out of their minds to try and come in where I am." I was mentally and emotionally well prepared for capture. Those CSAR professionals are simply astonishing. Ten minutes after this authentication I started hearing a helicopter approach from the west - it wasn't until later that I realized there was more than one involved in the rescue attempt, in fact there were two MH-53s and one MH-60. I was prepared to try to get them to land on the Western field because that would have been a little farther from the road.

The "Sandy's" had already established an authentication code that would alert the pilot to activate the strobe. Zelko was busy tracking the helicopter sound starting to go a bit towards the north of his position when he heard the signal to activate the strobe. Zelko came out of his hole up site just enough to hold it slightly off the dirt. Keeping low profile was essential - otherwise his figure may be exposed. He still needed to maintain as low a "signature" as possible as this was the most dangerous and risky moment of all, and things could instantly go bad again.

He activated the strobe; all while monitoring the radio, with time clicking by

and no word from anyone. Then the "Sandy" came up and said:

“We’re not getting your strobe.”

When Zelko heard that call he slid back down into the best hiding position possible, cautiously examined the strobe and determined it was not working. There was no backup covert device. He made a radio call that the strobe was inoperative then Sandy came up and said:

“Well, can you see the helicopters? Can you give them a vector?”

They were north of his positioned and Zelko radioed back:

“Yeah, I think you guys are north of me a couple of miles, come right, come south.”

And it was then that he noticed that there was other airborne activity in the area. With a search light on! He visually saw the Serbian airborne search activity more or less in the same area where he was tracking the CSAR helicopter.

This was very weird because there are no confirmed Serbian air activities in the area. Serbs did not have helicopters with the night flight capabilities. To fly in the zone of potentially active enemy airplanes presence was simply highly unlikely. Most likely Zelko got confused with reflection of the light or illumination from the helicopters.

That threw me off for a moment and it wasn’t until I heard the sound of the helicopters moving away from where the slow-moving airborne spotlight was that I knew for certain the light was not from a friendly. I heard Sandy on the radio once again; “Vega-31, give us a pen gun flare.”

This device was developed in the Vietnam era to penetrate foliage. It shoots up 250-400 m but he hadn’t prepared the one that was in his evasion kit. He reached it in few seconds. It was extremely well packed and while he started to unwrap the packaging two thoughts came to his mind...first, he wasn’t comfortable firing a flare 300 m up in the air because that was definitely going to compromise his position, and it would take him too long to prepare that item. He got very uncomfortable with the objective area. He decided; *“This needs to happen now, or helicopters need to go away and try again another time.”*

The co-pilot of the lead MH-53 he came up on the radio and said:

“Hey Vega-31, if we’re this close, just go overt.”

Zelko replied:

“How ‘bout a regular flare.”

He had that flare out and prepped in about 4 seconds. These are the standard ones, with a day end and a night end. As he was prepping the flare, the thoughts were which side to use. The day end is smoke, the night end is a flame, yet with the day end, there’s a little flame as the smoke burns which could be picked up by the night vision devices helicopter pilots likely had on.

To be certain there would be no further delay, and so that they would acquire the signal without having to search, Zelko opted for the night side and popped it. Just in case he stayed at ground level with body half protected by the sloping side of the embankment right where it was coming up to the flat part of the farm field. He held the flare just above the dirt and let it burn for about two seconds and then snuffed it out in the soil.

The helicopters instantly saw the flare and had eyes on pilot. They made an immediate radio call for pilot to “put out the flare” because in that darkness it was “blooming” their night vision devices, making it harder to see the survivor. Zelko didn’t receive that radio call because he was using the radio’s earpiece, which kept popping out with any head or arm movement.

Fortunately for them, Zelko killed the flare quickly. Helicopters were probably a 1.5 km away from his position when they saw the flare. At that moment they determined the MH-60 would try to make a quick grab and go. They were monitoring the considerable amount of Serbian search activity right there in the objective area, which was positioned nearly on top of downed pilot, and were still not 100% it was the real Vega-31. Just in case, several gun sights were fixed at the center on pilot during pickup.

Normally, even helicopters like to set up an approach, but that crew decided that there is no time for the classic approach. Flying skills and nerve of rescue helicopter crews are extraordinary. USAF CSAR pilots are cream of the force. They auto-rotated into the black hole of nothing. In a situation like that there is no depth perception, there is no horizon, and they had difficult time even judging

distance and closure rate to the ground. MH-60 peeled off and landed pretty much where the pilot hoped they would. The helicopter came down just to the west of him, about a rotor arc away. It was so dark that Zelko couldn't see them until they settled and the very top of the helicopter became barely illuminated by static electricity generated from dust hitting the rotors. The Pararescuemen – Para Jumper (PJs) came out while Zelko was waiting in a low crouch, non-threatening position. Two non-distinct shapes appeared out of blackness, approaching from his left. Zelko didn't see these parajumpers until they were maybe 3 m away. To him, they looked like aliens with their helmets and night vision devices and weapons. The PJ team leader came up to the pilot, grabbed him for the upper left arm and pulled toward him. He was doing a visual identification of Zelko's profile. That was the final authentication. Finally, they were absolutely certain it was Vega-31 and not a trap. PJ yelled to pilot:

"How're you feeling Sir?"

Zelko yelled back:

"Great! Let's get out of here!"

PJ gave Zelko a tug and said:

"Your PJ's are here to take you home."

Zelko followed them to the chopper. They all jumped in and off they went. From eyes on the survivor, to auto-rotate into the black hole, PJ's out and all of them back in and flying, it took them 90 seconds. Forty five seconds on the ground… That was very fast. From the time Zelko pulled his ejection handles to five minutes out of Tuzla, rescue team base in Bosnia, just west of the Serbian border and the same place when they landed, almost eight hours had elapsed.

From a CSAR perspective, it was a very long time.

Nobody in NATO command expected that some of their airplanes will be shot down so there was no prior search and rescue plans available. CSAR team was not even in the proximity of Yugoslav territory. The nearest one was in Brindizi, Italy. The Vega-31 event was a wake-up call for everyone involved in Operation Allied Force.

Extensive post rescue debriefing by JPRA - Joint Personnel Recovery

Agency team was a place to put all thoughts what went wrong and what went good. Overall communications were enormously frustrating for everyone, from very limited or no SATCOM capability, to almost non-existent secure voice capability. There were never rehearsed a CSAR Task Force Operation of that nature before. It was put together and executed ad hoc and on the fly.

From the evader point of view there was also a great deal learned. During Zelko's debrief with JPRA, they asked what three things he would have liked to have had. Zelko responded without hesitation:

1. STU-III phone,
2. night vision device, and
3. one-day shopping spree at LL Bean!

The idea of the STU-III comment is to have over-the-horizon, secure voice, giving the evader total situational awareness of what the CSAR was doing and what was the plan. The night vision device would have enhanced situational awareness of the objective area. And the LL Bean remark was to emphasize that there is a lot of very useful survival equipment out there in the civilian market. All these things would have greatly assisted Zelko to be the best survivor/evader possible. The survivor / evader can be a vitally important part of the CSAR Team and can make tremendously valuable contribution, having enormous impact on the success, or failure, of the CSAR.

Another lesson learned: Training and Preparation. This is all about Motivation and Determination. In this scenario there was not the luxury of time, there was no time to think about it or consider it, no time to reference the owner's manual. There was no time for uncertainty about what to do and how to do it. This event started very suddenly, unexpectedly (that an F-117 would go down), and violently - and for the next near 8 hours, until the helicopters were relatively safe (5 minutes out from the base in Bosnia), there was no time for hesitation; there was no time to flinch.

The mystery of Radar Warning Receiver (RWR)

The one can assume that there were no RWR installed in F-117A which is surprising. The F-117A continues to be one of the most intriguing aircraft ever built, even nearly a decade after it was officially retired, and more than 30 years after it was originally unveiled to the public. Maybe one of the most obscure and enigmatic details of the "Black Jet" is an elusive component called the Radar Locating System (RLS). For an aircraft that survives on its stealthy shape and coatings, these flip-down antenna arrays seem to deviate drastically from the F-117's modus operandi. But then again, the impetus for their existence may make more sense than not-that is if they really existed at all.

The F-117's Radar Locating System consists (as far as known from one existing drawing) of a pair of small planar antenna farms located under the aircraft's wings, about 3 metres (approximately 10 feet) from the wing roots, near their leading edges. The idea behind the system seems to have been that the F-117 pilot, who would normally retract all the jet's antennas when moving into hostile territory to minimize its radar reflectivity, could activate the system and its antennas would pop down into the airstream. Once deployed, they would work as a radar homing and warning receiver (RHWR or RWR), not only notifying the pilot of an enemy radar's presence and type, but also its direction and maybe even its general location.

Based on some accounts, the RLS seems to have been more about using the F-117 for the destruction of enemy air defences (DEAD) role than just avoiding enemy emitters and was possibly part of a program that aimed to see the F-117A dynamically go after radar and SAM sites as a secondary mission set. Based on the information available, it may have also had a recording function and could have given the aircraft a secondary signals intelligence collection capability as well.

According to one source, the array appears to be set up for spiral omni-directional electronic support measures (ESM) antennas, roughly 50 mm in diameter, which are typical for 0.2-18GHZ surveillance coverage, and they can be specifically tuned to different bands. Because of their wide spacing on each side of the jet's wings, the two sensor blocks/arrays coupled with the forward

motion of the jet would provide direction finding ability. In other words, at least the threat emitter's bearing could be identified, and possibly its range. This would be especially useful for finding and attacking newer road-mobile SAM systems like the S-300 that were emerging at the same time the F-117A was operating under high secrecy in the Nevada desert.

Today some of the most powerful capabilities that a combat aircraft possesses, especially the stealth kind like the F-22 and F-35, are their abilities to detect, classify and geo-locate threat emitters and other components of an enemy's integrated air defence systems (IADS). This is done via antennas placed all around the aircraft, under its stealthy skin. These conformal arrays are tied to high-speed computers that use interferometry, a large threat library, and other methods to give pilots-and even other aircraft connected via data-link within the battlespace - a real time tactical "picture" of the electronic order of battle around them. RLS seems like a very early and somewhat poorly conceived attempt to give the F-117A a fraction of this capability. Because conformal arrays and their composite coverings were not available at the time, the flip-down method was likely used.

The likely problem with the system was that it drastically increased the F-117's radar cross section when in use, as its flip-down antennas compromised the jet's smooth ventral surface. This is an especially bad attribute when it comes to maintaining a very low radar cross section for the critical forward hemisphere of the aircraft. The likely result was the F-117's radar signature bloomed drastically when the RLS was activated. As such, the system would not only blow the Nighthawk's cover, but it would also turn it into a target. Not just that, but it would have only offered a "snapshot" of the electronic threat environment around the F-117A at any given time. That's because the system would need to be retracted quickly, or it would turn the jet into a sitting duck while operating in enemy airspace.

By most accounts, it seems that the system was either just part of a test series or was only used for a very limited amount of time operationally, and how many jets it was installed on remains an unknown - that is if it ever existed at all.

Some veteran F-117A maintainers seem to remember the quirky RLS trap doors pretty well. They even have mentioned that they were known to sag, which would not only hurt the jet's stealth capabilities, but on dark nights that often were prime operations time for F-117 missions, partially opened RLS

doors could be a hazard for maintainers foreheads.

Not just that, but the RLS is prominently featured in the F-117's "Dash One" operating manual. It is not only mentioned, and its abandoned control panel identified, but its location is also shown clearly in a diagram of the jet. You can see the mentions below, and the entire manual is available online here.

It has been noted that by 2006, the system was not listed in official hazard and crash responder’s documents. The diagram showing the RLS doors are still there, but it does not identify it as being something that is accessible like the rest of the aircraft's retractable antenna, so it seems as if the doors were permanently sealed or filled-in at some point in time. This could have occurred during a depot overhaul or upgrade.

It seems that the Radar Locator System existence is still highly doubted by some - including the man that largely oversaw the development of the jet - senior Skunk Works engineer and F-117 program manager Alan Brown.

There is only possibility that the USAF made the modification themselves without Lockheed’s knowledge, but that itself is impossible to believe, knowing how well we followed up with the airplane in the field. Lockheed Skunk Works always had a cradle-to-grave philosophy in terms of follow-up with its products in service."

F-117 program manager, Sherm Mullin, who took over F-117 program stated that RLS "it was never put on the F-117A. Although he did mention that it could have been a concept from a study that occurred from 1984 to 1985 that apparently went off the rails conceptually and was disbanded with prejudice as a result.

During roughly that same time period it is known, although not well documented publicly, that the F-117A was tested with some fairly elaborate modifications. This supposedly included a handful of sensor systems in addition to the jet's stock Infrared Acquisition and Designation System (IRADS). We know that passive electronically scanned array (PESA) radar was flown on one F-117A in a specially-built radome fitted on the Nighthawk's iconic wedge-like nose. Maybe RLS was one of the other mods that was deemed successful and was accommodated for in some F-117s built, but never fully installed. As a reference, the reader can see the Figure 7-14 in the previous chapter to get an

insight into the F-117A cockpit.

As there are multiple contradictory information in the available literature the authors will to the reader to make own conclusion is that F-117A which flew into combat over Yugoslavia, had or not RWR installed (**Figure 7-15**).

Combat Search and Rescue

The NATO air planners were concerned about the possibility of allied aircraft being shot down. They recalled how several NATO aircraft had been shot down in earlier Balkans operations. On April 16, 1994, a British Sea Harrier aircraft was downed by an SA-7 missile near Gorazde, Bosnia. A year later, on June 2, 1995, a Serbian SA-6 brought down a USAF F-16 pilot, Scott O'Grady, over western Bosnia. Both the British and American pilots were rescued. On August 30, 1995, near the town of Pale, Bosnian Serbs employing a surface-to-air missile scored against a French Mirage 2000K. U.S. aircraft flew ninety-two dedicated sorties in support of recovery efforts for two pilots until officials confirmed that the Serbians had captured the two-man crew.

On the night of March 27, a 20th SOS crew, including Captain Cardoso as flight lead for the rescue package took off in an MH-53M. Their call sign was Moccasin 60. One wingman, Moccasin 61, was an MH-53J from the 21st SOS. The other wingman was Gator 07, an MH-60G from the 55th SOS. As directed, some other special tactics personnel were dispersed among the three aircraft.

As the flight of three helicopters proceeded to Tuzla from Brindizi during the day, the crews checked in with the NATO E-3 Sentry airborne radar on station and overseeing the strikes that evening. The weather over the region was poor, with mixed rain showers and low visibility, and many strikes had been cancelled. Cardoso and his group landed at Tuzla and taxied to the refueling pits to fill their tanks. As they were doing so, the crews aboard Moccasin 61 and Gator 07 heard a Mayday call on the UHF "Guard" (military aircraft emergency) frequency.

Immediately, aircraft commanders went into the Tuzla command center to determine what was going on. There they were told that an F–117A had gone down in Serbia. They quickly began to formulate a recovery plan and tasked intelligence for the most accurate location of the pilot. What was in the minds of the crews was "*a Stealth just got shot down and now [they] want us to go in there?*" While the immediate plan was not clear, the crews knew what they had to do and would figure out a way to get the pilot out of Serbia.

The requested information promptly flowed into the command center. Intelligence sources indicated that Vega 31 was down near Novi Sad, Serbia, an estimated 90 miles from Tuzla. Those sources also reported that the Serbs

realized they had shot down an F-117A and were scrambling to capture the pilot. Several flights of A-10s and other supporting aircraft including F-16CJ, F-15 and E-6 were being launched to assist in the rescue.

With that information, Lt. Col. Laushine, commander of 55 Special Operation Service and rescue mission commander, directed his task force to take off and head north to set up a rendezvous with the A-10s near Osijek in northeast Croatia. The three helicopters quickly launched and headed north. In this area, at least, the air was clear, and night visibility was good, although the moon was slowly setting. En route, though, they had difficulties establishing communications with the A-10s and other support aircraft as Laushine tried to organize the recovery effort.

Meanwhile, Zelko had been able to determine his location and had securely passed it to a C–130 orbiting over Kosovo. The C–130 crew quickly forwarded it through intelligence channels to Laushine. The reported position, validated by the A–10 flight lead, Capt. John Cherrey, who had established radio communications with and authenticated the survivor, indicated that Vega 31 was on the ground just south of the city of Ruma, 25 miles farther south. This was much closer to Belgrade, the heavily defended Serbian capital, and necessitated a complete rework of the recovery plan as the helicopter crews quickly entered Zelko's reported GPS location into their navigation systems.

To save fuel, Cardoso directed his flight crews to land their helicopters and dismount some ODA troops to provide site security. Meanwhile, Cardoso and his team built a new route to the survivor while the crew of Moccasin 61 coordinated for a MC-130P to refuel the helicopters. Once that was worked out, the helicopters re-launched, quickly rendezvoused with the tanker, just 250 m above the ground, and took on fuel as ground fog and low clouds were forming in the area. They repositioned to a holding point west of Ruma but still in Bosnian airspace and awaited the arrival of Cherrey's flight, which would escort them in to the survivor and provide top cover against any threats that challenged them.

Finally, the approval to enter into Serbian airspace came and descending to 15-20 m above the terrain, the CSAR three-ship proceeded inbound toward the pilot location. Several times, Cardoso increased his altitude to 30 m to avoid obstacles and populated areas. Throughout the night, the helicopters had been operating mostly in clear air. As they turned inbound to Zelko, though, they

encountered a layer of low-hanging clouds, fog, and rain. As visibility rapidly deteriorated, Cardoso and his crew, already wearing night vision goggles, began utilizing the forward-looking infrared radar (FLIR) system to proceed.

As they entered the low scud, A-10 flight could no longer see the helicopters to provide direct fire support. They themselves were being engaged (as they claimed) by SA-6 missile batteries. The author does not have any information that some of the Serbian mobile batteries has been detected the airplanes. Also, F-16 launched a HARM missile toward the one of Serbian radars (unconfirmed from the Serbian side). That may be the light that was seen by Zelko, describing the “search light” looking for him. As confirmed, there were no Serbian aircrafts in the air that night.

Entering the scud at about 20 m above the ground, the two other helicopters held tactical formation on Moccasin 60 so that they did not get separated while so dangerously close to the ground. On board all three helicopters, gunners and flight engineers were earnestly scanning for immediate physical threats such as trees, towers, or power lines - anything that could damage or destroy a helicopter - as well as Serbian forces. Suddenly, one of the crew members spotted an uncharted power line in the haze, just ahead and level with the helicopters. He quickly shouted, “Wires! Climb! Climb!” Cpt. Cardoso immediately reacted and pulled back on the controls, flying his helicopter up and over the threatening wires. The other two crews maintained formation and also avoided the threat. Once clear of the wires, Cardoso descended the flight back down about 30 m and proceeded toward Zelko.

Approaching Vega’s location, the helicopters encountered Serbian spotlights looking for them. There is no confirmed information from the Serbian side that any of the units at the vicinity used any search lights. About 5 km from Vega 31, the CSAR team spotted three Serbian trucks evenly spaced on a road as troops searched for the F–117A pilot. 3 km from Vega’s location, the rescuers contacted the survivor, but they could not see him. Vega’s infrared strobe was inoperable, and he couldn’t locate his pen-gun flares. Cardoso’s team told him to fire his overt flare. Vega did so, as we saw from the Zelko’s description. Immediately, the helicopter took position around and the PJ’s picked up Zelko.

Rejoining the Pave Lows, the MH–60G and the 53s flew a different route leaving Serbia than on the ingress. As they approached the border with Bosnia they observed Serbian antiaircraft fire in the vicinity of their previous flight path.

Without being able to see the aircraft, the estimate of the crew was that the Serbians appeared to be firing volleys in hopes that the helicopters were flying the same route as before. After the five and one-half hour mission, Cardoso's team landed safely at Tuzla at 03:54 (**Figure 8-44**).

US rescue team reported about the search light like "in the WWII". Serbia didn't have that kind of equipment, except in museum. If there were any lights during the mission, it may be the vehicles high beam lights or individual but powerful flash lights. The 3rd battalion has not been active that night since downing F-117. Some other battalions possibly used their radars to illuminate the airspace in search for the enemy airplanes but in general on the Serbian side, it was quiet one. Some of the army air defence units with triple 20 mm cannons occasionally opened fire if something suspicious is in the air and some infantry units with their heavy machine guns may also opened fire but there is no official records that any of the units fired that night. In the area of crash, some units of the Serbian 453rd armoured brigade were located but they were not involved in any fire reported by the rescue mission. Military police from the armoured brigade and police searched the area and found stuff that Zelko left behind.

In some books, publications and documentary movies, authors describe Serbian air defence as an integrated, modern and formidable and the Serbian airspace as the "heaviest defended space on earth" but later there were contradictory information that NATO airplanes can easy "deal" with Serbian obsolete SA-2 SA-3 units. The truth is that exaggerating the opponent capabilities, NATO wanted to raise their own achievements and capabilities which were actually not at the presented level. As always, through any wars so far, the very first casualty of war is the truth.

Analyzing the Serbian activities, one thing is evident: Serbian side was not prepared for the case that the enemy airplane is downed, and pilot landed on their territory. There were no developed plans how to react, how to organize the search forces. It was on the local level to form the search parties, often involving locals. There was some knowledge of the CSAR mission procedures on Serbian side, but it was merely in the intelligence branch but not widely distributed among the field units. Local army units in the vicinity may be used for terrain search, assisted with the police forces but police were also tasked to prevent local to go in search on their own. The Serbian concern was that if the pilot is captured by the local civilians, then no Geneva Convention will protect the pilot but also in the case of shootout with the rescue team, it may be unnecessary

casualties.

For Serbian side, this operation was also learning curve. US CSAR manuals and procedures were studied, and the theatre teams formed based on the territorial locations, which includes part of the regular army, parts of the state security forces and police and local hunter groups.

Figure 8-40: Lt. Col Dale Zelko (Source: USAF)

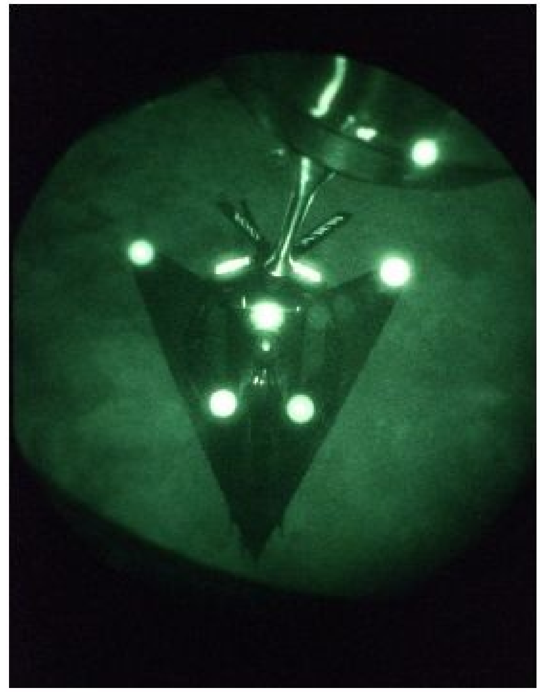


Figure 8-41: F-117A night refueling. (Source: USAF)

Figure 8-42: Command center Strazevica- hit many times, including Zelkos hit but never destroyed. (Source: NATO)

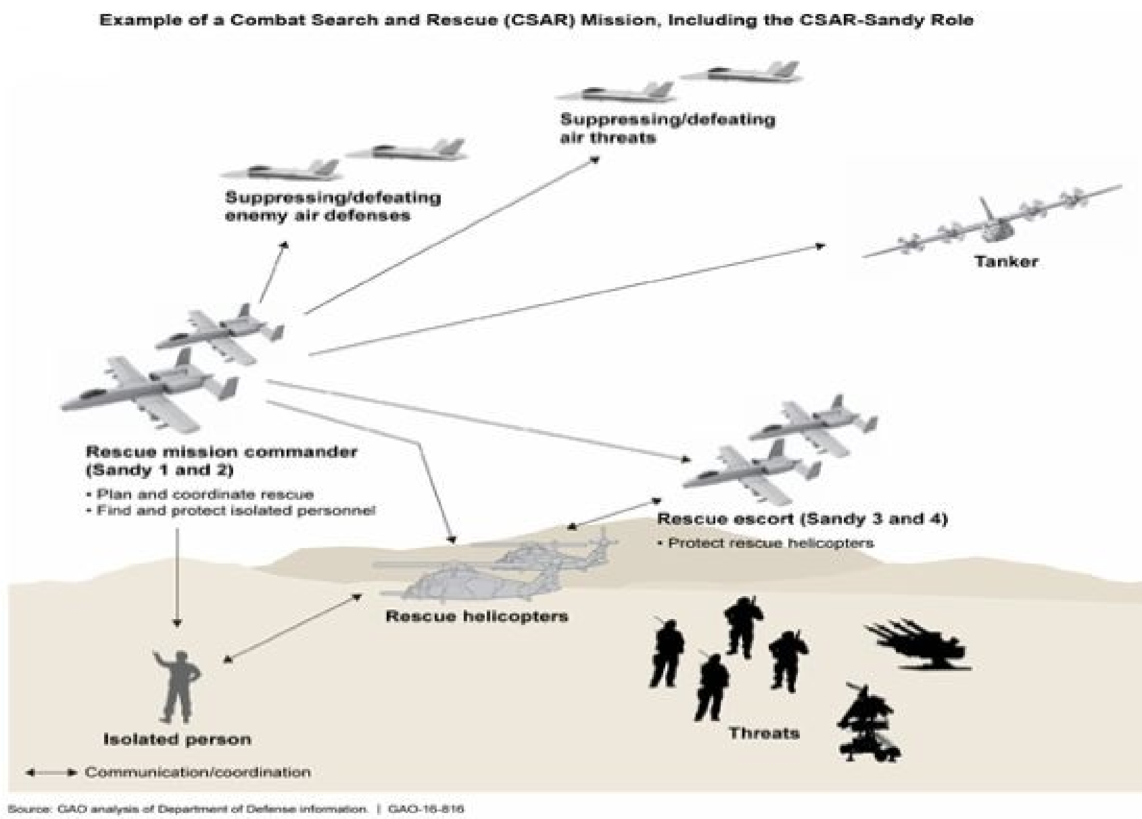


Figure 8-43: CSAR operation (Source: USAF)

Figure 8-44: CSAR team which rescued Zelko.
(Source: USAF)

F-16CG

May 2

From Aviano base a group of two pairs of two F-16CG entered into the Yugoslav airspace from Croatian side. The group leader call sign for the mission was Hammer 34. From west-by-north west direction, the other group of 4 airplanes also entered into the Yugoslav airspace. Two groups of airplanes, approaching from the different bases formed a dynamic combat group which main task was to search and destroy missile batteries in the northern part of Serbia, the batteries which defended the approaches to the capital. The F-16CG group from Aviano, as per intelligence reports obtained before the mission, will try to enter into the destruction envelopes of the missile batteries previously identified and provoke the batteries to turn on fire control radars. This will be detected by the SEAD group which will launch anti-radiation missile. Emissions of the fire control radars will be recorded, and exact location of the unit pinpointed so that the airplanes can attack with laser guided bombs. This is basically the standard counter SAM tactics.

3rd battalion was in the area. That night the combat crew consisted of Major Bosko Dotlic commander; Sub. Lt. Miodrag Stojanovic, deputy; Maj. Milorad Roksandic, missile battery commander; Sub. Lt. Tiosav Jankovic, missile guidance officer; Sgt. Igor Radivojevic, manual tracking officer on F1; WO Dragan Matic, manual tracking officer on F2 and pvt. Sead Ljajic, manual plotting operator. That night radar emission imitator was connected and ready for use (**Figure 8-47**).

About 30 minutes before midnight, P-18 surveillance radar detected the target in the distance for which the crew turned on the fire control radar for 10 seconds to illuminate it. It was evident that there are activities in the air. One of the missile battery tasks is also to try to illuminate aerial targets to “scare” them and chase out of designated space. After receiving the signal that it is illuminated by the fire control radar, the aircraft quickly changed direction and left. Most likely the pilot informed his combat and control center about the radar and probable direction.

About 02:00 on VIKO display, the crew commander noted six to eight blips,

scattered in small groups on azimuth 300 and distance of 80-100 km. One smaller group has been detected in the area of city of Valjevo, down south. At one moment the group that was north-west from the battery, disappeared from the screen. Shortly after, one of the airplanes appeared on azimuth 310 and 30 km distance.

"Azimuth - 310… Search!" Maj. Dotlic ordered.

The crew was calm but everyone felled that something is going on…that is "something and somebody" in the air hunting for them. Major Dotlic didn't allow the rest of the crew to look at his screen, rather to be concentrated to their tasks. After a few screen swaps, Dotlic saw that the airplane has a stabile course toward them, with very little parameters. He quickly issued a few orders to adjust the azimuth *"2,5 degrees left from the existing one*".

Battery commander quickly turned control wheels on UK-31 in attempt to direct the missile guidance office by azimuth and elevation. At that moment, Low Blow radar is turned on. Missile guidance officer rapidly moved his control wheels positioning antenna to the target direction. Lt. Jankovic saw the target on his screens and at the moment when one of the tracks started to fade from the screen, he noted a smaller one, slightly right from the screen marker, with the RCS similar to MiG-29 fighter. He quickly realized that both of them were on the same course and height and that the second one, which were slightly closer, is the real one and the other one was a decoy. He quickly put the marker crosshair on the target on his screen, providing possibility to transfer to the manual tracking and handed over to the manual tracking operators on F1 and F2. The target speed was about 250 m/s with the parameter 4.

When the target was 17-18 km major Dotlic issue an order to launch 2 missiles and method of guiding:

"Launch!"

Laud bang followed by the missiles blast-off from the launching platform. The second missile, like in the case of F-117A, didn't acquire the target and went on ballistic trajectory. It happened for the second time and that was the thing to worry about. Something was wrong with the guidance blocks and coordinate system. It is standard procedure that when the new crew take the shift, missile guidance officer checks the functionality of the station. All parameters so far

were satisfactory and there were no indications pointing that some of the equipment is malfunctioning. But something was wrong because the missile was not able to “take” the guidance commands.

Dotlic followed the missile on F2 screen:

> *“At the moment when the missile reach the target, I saw a conical shape which covered the target, which correspond to the warhead explosion in the target proximity”*

Missile guidance officer reported:

> *“Target destroyed, distance 11-12 km!…”*

It was school example of the warhead explosion in the proximity of the target. Conical shape on the radar screen corresponds with the warhead fragments covering the target. At that moment VIKO showed that the target is still in the air and maneuvering, heading to the east direction. The target was not destroyed! Major Dotlic ordered to turn off fire control radar. Only the radar imitator was still on. From the brigade command post, it was observed that the target changed direction rapidly, taking a course toward Bosnia. Obviously, the airplane sustained a great damage, tailing the long black smoke tail behind and now is trying to escape from the Yugoslav airspace in the western direction. The whole crew hoped that it will not get to the Bosnian airspace and it will crash on Serbian territory. If he crashes at the Serbian territory, that it will be second material proof that the enemy airplane was downed. Five minutes after the hit, Maj. Stankovic with the cherish voice informed:

> *“Bole! (*nickname for Maj. Dorlic*), he crashed!!!”*

Not long after, the crew got confirmation that the airplane crashed in the vicinity of Nakucani village, not far from the city of Sabac - at the Serbian territory (**Figure 8-48**, **Figure 8-49**).

The missiles fired by the 3rd battalion bear the names “Natalia” and “Zivadinka”. After the first downing, the crew decided to give to every missile a female name - name of spouses, girlfriends… “Natalia”, 5V27D missile, launched from the 5P73 s/n. 13013 had a hot date with US pilot. This time it was date with Lt. Col. David Goldfein F-16CGs, who then commanded the 555th Fighter Squadron and led the first of many missions of Operation Allied Force

over Serbia. Besides he was the squadron commander, Goldfein family is strongly related to the Air Force as both his father and brother are high ranking officers. At the time of this book is written, he is a four-star general and Chief of Staff in USAF.

During the engagement, radar imitator was on, constantly covering the “Low Blow” radar, providing the protection and cover against HARMs. After the engagement, two HARMs were found not far from the battalion radar post.

Hammer 34

The SAM launch sites had proved to be a constant threat in Serbia, disappearing and reappearing and NATO was never sure how many of them are actually operable at any given time even they claimed that a significant number have been destroyed. This one which appeared right under the 555th squadron's route as it flew into Serbia, on a night mission to destroy enemy air defenses was battle hardened 3rd battalion (**Figure 8-46**, **Figure 8-50**).

By F-16 CG pilot, Lt. Col David Goldfein (**Figure 8-47**), own words it wasn’t an easy task.

> *"I became a very expensive glider pretty quick,"*

He saw the flak clouds from the anti-aircraft fire that was trying to zero in on his damaged plane. One shoulder launched SA-7 missile has also been fired on him. His airplane was crippled, and it was a matter of seconds is he going to eject over Serbian territory or over “friendly” Bosnian territory.

He felt a stinging sensation on his hand and he looked down to find blood welling from a minor shrapnel injury.

He waited to eject so he would have just enough time for his parachute to deploy while spending as little time as possible as a floating target. The ejection mechanism worked flawlessly.

> *"That's when your training kicks in. It was a full-moon night. You don't want to be highlighted (in the sky) too long."*

After landing in a "perfectly plowed field," he rolled and popped off his parachute. Helmet still on, he grabbed his things and headed for a ravine. The ravine sloped down at a steeper angle than he had expected from his hasty

survey, and he tripped and fell face first.

> *"My stuff was like a raft in front…I was riding it like Indiana Jones down to the bottom."*

He collected himself and then made radio contact with the fighters still circling above. He was located at 03:55.

> *"My first call was answered by my buds who were with me. There wasn't a minute I didn't hear jets overhead, and that was very comforting. There was absolutely no question in my mind I was getting out that night."*

As his training had taught him, he dumped anything shiny that would reveal his location and traveled along the edge of the plowed field. If the field had land mines, he thought, the farmers would already have dug them up.

> *“The countryside looked a lot like Indiana or Ohio farmland. There were lots of dogs and roosters up and awake and sounding off at 2 a.m.,".*

After walking about three kilometers, he found a relatively remote cleared area.

> *"I had to find a good spot to stay hidden and coordinate the rescue…It was just… 'Don't screw it up; don't get in the way"*

He once again communicated his position, and then, from his hiding spot, heard a rustling sound and looked in the direction of the noise.

> *"Whatever it was, it reared up on its hind legs ... I saw beady eyes…I say it was a Serbian tiger, but my buds said it was probably a field mouse."*

He ran for a distance, which turned out to be a good move because he found a better landing spot. Rescue mission was scrambled right away. CSAR team was supported by scores of combat F-16, EA-6B, A-10 and support aircrafts. When the rescue helicopters arrived, it brought Serbian small arms fire with it. Some of the local opened small arms fire from carbines and assault guns but they were not match for the machinegun fire from the helicopters. Within seconds of its arrival, Goldfein was in the helicopter. He was in Tuzla airport at 4:45. A later inspection revealed five bullet holes in the helicopter fuselage (**Figure 8-51**).

Goldfein said he wanted to fly immediately afterward, but his commanders told him to wait a day. Although he flew the next day, he points out that pilots in Vietnam often flew the same day they were rescued, and they didn't receive a hero's welcome when they returned home.

Something VERY BIG was in the air...

May 19

Lt. Col Anicic and his crew took the afternoon shift at 16:00 on May 19. That day, Russian envoy, Victor Chernomirdin was at the visit to Belgrade to discuss the situation with Serbian president Milosevic. Indication was that it will be the quiet day but as soon as the Russian plane take off and clean the Serbian airspace, NATO will strike again. Around 22:30 Chernomirdin left. The crew was in the Readiness No. 2 since 22:50, meaning no immediate danger. The crew took-off their flak jackets and helmets because it got warm in the UNK cabin. It was weird to the shift commander that the Readiness No. 2 was declared at the time when most of the previous days it was Readiness No. 1 in expectation that NATO strike force will appear.

Serbs developed an ingenious solution to "upgrade" the capacity of the light AA systems. The M53/59 Praga is a Czechoslovak self-propelled anti-aircraft gun developed in the late 1950s. It consists of a heavily modified Praga V3S six-wheel drive truck chassis, armed with a twin 30 mm AA automatic cannon mounted on the rear. The system is optically aimed and can only be used effectively during the day with good weather conditions. So, for the night operation it was basically useless. However, technical department decide to combine the obsolete AA system with the short-range missiles from MiG-29. The rail was mounted on the top of the truck and MiG short range IR missile mounted (**Figure 8-52**). What the meant is that the battalion have a support of the additional firepower for which there is no need to use fire control radar because the missile is guided by the heat emission of the jet engine. It was like to have shoulder launched platform but with the range of 20 km. Improvised solution, but effective if employed correctly.

For the night of May 19, Praga defended area in azimuth 10-120 degrees. Everything was in surprise. In USAF jargon, this kind of action is known as a "snake in the grass".

Suddenly, at 11:00 the brigade command posts ordered Readiness No. 1. and the crew quickly took their positions ready for the combat engagement. Lt. Col. Anicic ordered that P-18 surveillance radar to be turned on. VIKO screen showed that there are numerous targets, 10-12 km distance - very close indeed! It was massive attack on the way. Fire control radar was not fully ready. That old technology needs some time to "warm up".

As the radar was not ready, the first "ring" was not engaged. The second

“ring” was about 25 km away.

Lt. Col. Anicic and Lt. Col. Milenkovic developed the tactic to use this modified Praga in ambush. In the case of engagement, missile battery will launch. Most likely, attack airplanes will try to attack the battery and that will be the opportunity for Praga to launch their missile on approaching aircraft. As Praga doesn’t have radar and the missile is the passive one, there is no danger that it can be detected and jammed before launching.

In UNK, the tension rose.

“Azimuth 180…Search!”

Lt. Col. Anicic ordered radar search on azimuth 180. There was target 17-18 km away.

“High – up!”

High voltage on the fire control radar is up…

“Antenna!”

The target is 15-16 km away.

Very quickly, within few seconds, missile guidance office Lt. Jankovic, found the target. Little turning of the wheels by azimuth and angle and the target is in the crosshair marker. The target is maneuvering, it must be that he detected radar emission and that is in the fire control radar sight.

One click of the wheels, pushed away from the operator, toward the station which mean that now the manual tracking operators have the target on their F1 and F2.

After few seconds, the next command:

“Target destroy with two missiles!…three point guidance!…” ordered Anicic.

Loud hissing, missiles booster motors ignition…and start…first missile blasted off from the ramp, five seconds later the other one…

Missile guiding officer reported the parameters, height, velocity…first missile, “Tanya” acquired the target…second missile “Ivana” acquired the target…guidance normal…distance to the target – 14 km…it was “school” shooting.

Suddenly, manual tracking operator on F1 commented said:

“What the f..k!!!...What is this?!!!

Blip from the screen was enormous, took almost the entire screen.

First missile exploded in the vicinity of target…than second explosion…13 km distance, azimuth 180 degrees. Bright explosion in the sky. The target was hit at 00:11.

“Target hit…both missiles!” operator reported.

“Take the high down!...Equivalent!” Lt. Col. Anicic ordered.

The next shift knocked on the van door. It was slightly after midnight. As the combat engagement is in progress, there is no shift change. The real danger was that at this moment two combat shifts were at the site and one well-placed bomb or missile may eliminate both!

The second shift observed the whole engagement visually…the missile launch…explosion in the distance…Modified Praga also launched their AA heat seeker missile.

Brigade operation center informed that there are helicopters in the air…something happened…something big otherwise, shy they should launch helicopters.

There are airplanes in the air from three directions… Swarms of them… After the launching, the UNK doesn't have indication that the missile ramp is functioning. Something happened. As the two missiles were launched at high elevation, the blasts created the crater and from the powerful force the 13 tons platform moved by 20 cm from the original position and one of the missiles fall from the launching beam (**Figure 8-53**).

Airplanes seem to feel that, and major attack is from azimuth 205-235. UNK can't launch in that direction from the other platforms because that is "forbidden zone" and the blast will damage the own equipment. There is a one of the strongest attacks since the beginning of the war and one of the ramps is out of service! From azimuths 300-330 and 150 - 180 there are numerous of airplanes. Anicic ordered to his deputy to emit from the radar imitator. Deputy commands are short…radar imitator performed emission form one target to another… Emission duration 5 seconds…than next target…no time for longer. Airplanes detected that they are illuminated but they don't know is that real fire control radar or imitator. Fire control radar illuminates one group and imitator the other one which comes from the "forbidden launch cone". The third group is not covered.

Anicic ordered search one more time and detected a pair 14-18 km away, heading out of the range. On the other side, from the back, the airplane is entering in the zone, distance 15 km. There is no time to launch and engage departing targets…next target - the approaching one.

As soon as the target is illuminated, the screen showed a lot of cluster… jamming…missile guiding officer reported that he can't see the target anymore. Lt. Col. Anicic ordered to turn off the fire control radar. The rest of the night only radar imitator was used. There were airplanes in the air but they didn't enter into the destruction envelope.

Something important happened that night…so many attempts to attack the unit, like never before. The sky "cleared" at 01:30 and combat crew ended their

shift.

Walking toward the unit camp, Lt. Col. Anicic tried to recapitulate what happened. How come that during the all engagement there were not a single HARM missile launched? The radar emission was very short. From the moment of detection, until the hit, the target passes only 4 km. That was the key. HARM shooters didn't have enough time to acquire the direction of the signal and launch the missiles.

The question is now: What was hit that night? Was that the towed decoy or radar target, or the real airplane and if airplane, than which one? There are many speculations about this and in the following paragraphs we will analyze this.

In one of analyses, Col. Vladimir Neskovic PhD, information system expert in the military technical institute, provided the combat engagement parameters analyze and combat engagement parameters calculations (**Figure 8-54**, **Figure 8-55**)

In the Serbian press it was declared that B-2 has been hit and crashed not far from the Serbian border, in the area of Spacvan forest, on the Croatian side of the border, about 15 km from the Serbian border.

The fact is that there is no material evidence that anything crashed. No publicly available photos, video or audio records. However, there are strong indications that something really happened that night.

In this book we will stick to the fact that it was aerial target in the air that night, which was engaged and hits observed. However, the following is the list of the facts and findings which correspond with the event. It is up to the reader to make their own conclusion.

- The crew had no idea what is in the air. For them it was just one of the targets which they picked up, based on the distance and altitude.
- Can B-2 be detected on SA-3 radar systems? The answer is yes. Even huge airplane by size, the Radar Cross Section of B-2 is less than 0.1 m^2 which is within the RCS detection capabilities of Neva system. (Note Figure 1-20 for B-2 RCS).
- F1 screen radar blip. The sheer size of something that the very experienced crew didn’t notice before or after. can that be from the real aircraft? the answer is yes. Can that also be from the towed decoy? the answer is also yes.
- Aerial speed of the target, height and direction was classic evasive path after the bombing mission.
- Immediately after the hit, position lights observed in the air in vicinity of the border with Croatia. It is not common practice that

aircraft in the vicinity of the enemy airspace turn on the position lights.

- Crash recorded at 00:23 on Croatian side. Capt. Ilija Vuckovic, radar operator on P-12 surveillance radar, under the 250th brigade command, at the position in the village of Karlovcic was able to track the aerial target until it disappeared from the radar screen at distance of 105 km and azimuth 275-280. From Karlovcic to the Spacva forest the distance is approximately 100 km.
- Unusually fierce attacks from the multiple direction immediately after. the battalion was never before engaged in the multiple coordinated attacks.
- Helicopters reported in the air immediately after, but without entering the Serbian airspace.
- Radio amateurs reports of unusual loud noise, the explosion and large fire on the Croatian side. radio amateurs were particularly active during the whole duration of the war and were one of the valuable source of information for the Serbian side.
- Croatian Zupanja radio and TV station broadcasted that something crashed in the forest than suddenly all reports of that stopped. there is no taped recorded report or hard copy on the Serbian side.
- Next edition of “Voice of Zupanja” newspaper published that the large airplane crashed in their area but promptly all examples are removed from the newsstand kiosks. Whereabouts of all issues are unknown to this day.
- Local fire department urgently sent to extinguish the fire in the forest. Firefighters reported of something big on the ground, no tail, no markings, burning. One firefighter reported that it looks like spaceship. the name of the firefighter is unknown to the authors.
- Local police called to secure the perimeter.
- NATO and SFOR increased activities from nearby Bosnia and passing to the Croatian side. This was reported by multiple sources.
- “Sanitized” area of the possible crash site for approximately next few months, with nobody local allowed in. Local police provided outer perimeter protection. Satellite photos of the are shows that beside the dense forest, there are few available local roads.
- Heavy trucks with the closed cargo space observed moving in and out form the area. This was reported to the Serbian intelligence by the multiple sources.
- Increased flight of the transport airplanes from Tuzla airport. Local residents reported and it was also observed with the surveillance

radars.

- After the war, at alleged crash site, in the forest, the small pond appeared, not recorded before the war on any map (see the photo from google maps and Yandeks with the different level of details).
- No B-2 missions over Yugoslavia conducted anymore until the end of the war even the combat sorties of the other aircraft were intensified. Deputy Commander of 509th Bomber wing, Steven Bashen, in one the interviews for the aviation magazine confirmed that the B-2 were retreated from any combat engagement against Yugoslavian targets since May 21, the day after the engagement. The same was confirmed in the book "B-2 Spirit units in Combat" by Thomas Withington on page 43. US commanders in the theatre stated that the Serbian sky was still dangerous at the last day of the was as it was at the first day and that the majority of the key targets were not destroyed and Serbian Air Defence, even crippled is still very capable and dangerous. Was that because there were no valuable targets for them or because of fear to loss the valuable airplane?
- Serbian security forces recorded emission on the emergency radio frequencies between the pilots and command center with the request to eject. Request denied until Serbian airspace cleared. The record "disappeared" from the secret service after the government changed in Serbia, as the authors were told. Transcript and whereabouts still unknown. This is questionable because Serbs definitely had the possibility to record the conversation on unscrambled links but also can be "fabricated" as proven later with the "fake" and "fabricated" radio transmissions in so called "B-52 downing".
- B-2 was in the air that night, bombing targets in Belgrade. Call signs for two airplanes were Stub 1 and Stub 2. This information is not verified. It is possible that Serbian side didn't record the proper names.
- Local communication employee in Tuzla witnessed that he heard the crew request to eject which was not granted until they clear Yugoslav airspace. The name of the employee was never published and is still unknown if the information can be treated as real.
- US annual report about the air force inventory didn't listed Spirit of Missouri in the Air Force yearbook…allegedly that was typo or editorial mistake, as explained by US officials. The name of B-2, Spirit of Missouri, appeared in the later edition.
- Pentagon is not publicly announcing the loss of any airplane until

the other side possess the material evidence such as a wreck or pilots. If the plane is damaged and crashed after or during the mission on the "friendly territory" it is considered lost to the mechanical problem or human error. In general. if we look this on the way that the missile hit definitely presented the cause for mechanical problem the Pentagon is saying the truth. If the reader at this point go back to the Chapter 7 Stealth Development, the one will see that when F-117 no, 702 crashed on July 11, 1986 out of the US military controlled areas and available to the general population, the entire area was cordoned, and the very last piece of wreck removed. The analogy is here…to think about.

- Register numbers and marks of the airplanes are recycled. In example, F-16CG from the 555th squadron which was downed over Yugoslavia appeared on the other similar airplane. B-2 with the identical number and name "Spirit of Missouri" was recorded during the initial campaign against Iraq in 2003,
- Brigade officially recognized the engagement of early morning on May 20, 1999 as an event which shot down B-2 and the victory silhouette mark of the downed airplane appeared on the UNK cabin door, beside F-117 and F-16 marks and, as of the time of this writing, is still there (**Figure 8-56**). It was also recorded that the higher commander ordered victory signs to be removed (as not appropriate as per the service regulation?) but that order created the protest from the battalion members and the signs were where they are before.

After the overthrow of Milosevic regime and government changes in Serbia and normalization of the relationship with NATO and US, US officially asked Serbian side four question which closely shows their interest in the Serbian abilities to detect the stealth…Lt. Col. Anicic had an opportunity to look at the original question in English. For this book that copy is not available but as an illustration there is a Serbian language respond to every particular question with the authors translation as an explanation (**Figure 8-57**):

<u>Questions 1</u>: What was the importance of the field visual observers for F-117 and B-2?

<u>Answer 1</u>: It is important to point in regarding to the visual observation that the aircraft mostly flew during the night, and B-2 on very high altitudes meaning that it is not visible to the visual observers.

<u>Question 2</u>: Refueling courses for B-2 - where the B-2 took the fuel from the aerial tanker. B-2 uses much different refueling system than F-117.

have you been able to distinct between F-117 and B-2 aerial refueling?

Answer 2: not provided in this document.

Authors comment: Answer is most likely provided in some other documents. Aerial tanker has the large RCS and it may create the single blip on surveillance radar and the refueling aircraft may be "masked" by it. Modern radars can make the difference.

Question 3: the basic question for B-2: where you been able to recognize and tract this aircraft during the flyovers of your territory?

Answer 3: According to our information, B-2 took off from USA and was escorted by fighters during the air refueling. The typical altitude was 40.000 feet at which the aircraft can avoid our air defence. How we detected and "listened" it…like every other aircraft, the aircraft must report to his own command when he enters into the combat zone. Every airplane had the specific call signs, extraordinary powerful radio and flew only during the nights. The aircraft reported to the air control command in Brindizi. Typically, he approached from the north direction and fulfill the missions north of the 45th parallel in the Belgrade zone as per defined targets such as Chinese embassy, Interior ministry building, Defence ministry buildings. We registered more than 10 missions.

Question 4: Can you track that airplane? Can you identify that airplane?

Answer 4: We can track targets up to 18.000 m altitude and we can identify that airplane as well.

- In one face to face meeting, US delegation visited the combat crew which downed F-117A. During the conversation 2005, WO Matic, F2 operator (than retired), showed them photos of B-2 as a victory mark on the UNK door…WO Matic asked them about the downing of B-2 and US representative was caught with that question and simply couldn’t “resist” looking WO Matic into the eyes and answer his question. Quickly, the conversation went to another direction.
- Alleged crash site in Spacvan forest. Azimuth of the cleared space more or less correspond with the recoded azimuth of crash (**Figure 8-58, Figure 8-59**).

Previously mentioned, there is lot of speculations but without material evidence or direct confirmation of US side that B-2 was lost, nothing can be taken as granted.

For the sake of clarification, there is evidence that something was hit that night…something really big. What was that “big stuff” and what if that

"it" crashed or not, is the subject for some other research.

"Intelligence games and throwing dust in eyes…"

The question is: Where all of those parts for F-117A finished and how might others have benefited from them?

The smouldering wreck in the vicinity of the village of Budjanovci was very soon, after the downing, scavenged for souvenirs. The 3rd battalion men took, of course, many souvenirs for themselves. The locals, especially gypsy's brought carts to salvage material they thought will sell for cash. To their disappointment, local scrap yards didn't want to buy composite material. They were interested only in metal. What happened is that gypsies found a original way to utilize stealth part - to cover their pig stays!

Engines, canopy, parts of wings were collected and majority of the parts which were left after the war are now in the depots of Belgrade Airspace Museum. Canopy and one wing are at the public display. There were also parts which were handed over to interesting parties - Russians and Chinese. Everything was shrouded in the veil of secrecy and there are no official documents about this, but it is certain that Russians got parts interesting for them and Chinese also got their "shares". After the war, it was observed that the area of downing and the village of Budjanovci was frequently visited by Chinese "tourists" who bought from locals whatever they can find that belongs to F-117A. The intelligence reports confirm that. It is interesting that even the pilot oxygen mask hose, which collected dust for years in the farmer's barn, was sold to Chinese "collector" for the price of the new wood stove!

There are no doubts that Chinese got parts which were thoroughly analyzed and gained knowledge used in development of their own stealth airplane. Russian institute made also analyses of the coatings and even one some of the parts are now in internal exhibition in Institute No. 2 for radio electronic. Russians wanted to confirm that their estimates about the radar absorption were correct during the testing of RCS for the stealth models.

The other thing which is more important is the changes of the procedures and rules during the combat engagements. Russian delegations were at the command post of 3rd battalion observing tactical procedures which were implemented in the new combat engagement procedures. Promptly after the briefings with the missile crew and step by step analyses, Col. Victor (Russian military observer,

second name not disclosed) sent to Moscow his notes through the Russian embassy in Belgrade. Russian thoroughly analysed the provided information and their reaction was very fast: the combat engagement of the 3rd battalion was used as an amendment package which were promptly implemented in the missile battalion tactics. The one can be sure that all interesting parties, such as Iraqis, North Koreans, Syrians and Iranians now possess all "know-how"… NATO has that too (maybe).

Col. Dani after the war placed a calculated disinformation in the documentary movie "21 second" that he modified the search radar so that it can detect the stealth airplane far away. Also ordinary kitchen microwaves were used to confuse the HARM missiles because the similar frequencies as the target engagement and missile guidance radar. His explanation was that "on the adversary propaganda, he used his own propaganda". However, there were absolutely not a single technical modification of the radar nor there were microwaves ever used by 3rd battalion for that purpose.

USAF officials immediately after the downing came with a multiple theories how it happened. Some reports speak about pre-arranged flight paths and that Serbs somehow found the pattern. Serbian spies tracked F-117 from the take-off, through Hungary and during the target approach. Serbian command used optical cables and mobile phones to transfer the information to the specific designated unit which launch the missiles. One report speaks of lucky shot when Serbians randomly fired missiles and scored. The other guessing that Serbs were able to penetrate into the radio communications between airplanes and command centers and pinpoint individual plane location… This is utterly nonsense!

It is true that Serbian side used wide network of informers and sympathizers, even some people who were directly positioned inside the base and had on time information about the preparation. In the book "Stealth Down" there is a short description of the "aircraft spotters" behind the fence who took photographs. Some of them were sympathizers of the Serbian side. Information about precise take-off time of the airplanes is promptly transferred to the Serbian side. Even media such as CNN or RAI covered a lot of times airplanes taking-off from different NATO bases so Serbian side was also closely followed the news... Flight paths through Slovenia and Hungary were monitored. Airplanes created plenty of noise, condensation trails in the sky above those countries provided clear vectors. Radio amateurs in the region were one of the information sources. Serbian side needed to calculate the flight time to estimate when the aircraft will be approaching the target. This sounds easy, but in practice was not such an easy task. Some of the information received definitely helped the Serbian side but by no means can be considered to have any contribution in the downing of stealth.

Reports that the missile battery commander knows that in his sector of responsibility the stealth will approach at the certain time is nothing but speculation. Why and who has done that, they know their own reasons.

The real truth is that old Soviet P-18 radar can clearly detect F-117 at least 30 km away. Fire control radar also can track stealth airplane even in the circumstances of electronic jamming. F-117A was not invisible to the radar… just the signature is not really high. Well trained and organized crew can routinely detect it 40 km away or more. That night, two other radar blimped were on the screen. What was that, it is known at the time of this book writing. Americans also put a part of blames to the mission planners using the predetermined paths in and out of Yugoslav airspace. As F-117A was flying alone without any fighter or electronic warfare capable airplane such as EA-6B and HARM shooters F-16CJ to cover the flight and mask the F-117A with the clutter which will show many blips on the radar and missile operator screens and masking the stealth to “disappear” in that clutter. In the post F-117A phase of the war, NATO extensively use this type of tactics, in most cases successfully blocking the Serbian air defence but not without casualties. There are two F-117A which were most likely damaged during the missions. One landed at Zagreb’s Pleso airport with the significant but not catastrophic damage. After the war, 2 unidentified by serial number, airplanes were disassembled, packed into the transport planes and returned to US. Why should anybody return the airplanes on this way? The only conclusion is that they were not able to fly over the ocean on their own, not air-worthy, due to the sustained damage. Upon their return, they were assessed and as the repair was not feasible they were placed in the holding ground and eventually scrapped.

The big question is how the parts that were handed over to Russians and Chinese may contributed to development of their anti-stealth capabilities and also development of the own stealth programs. Many US high ranking officials were not overwhelmingly concerned about this possibility because F-117 was very well known and many publications and articles were available at that time. Burned wreck and destroyed electronics were not major source for concern. For USAF It was “yesterdays” technology and from then, US developed far advanced next generations of the Stealth. Serbian side never published any details what has been found and what was “delivered” to the friendly countries. However, after the war, when the regime of president Milosevic was overthrown and relationships with NATO countries normalized delegation from NATO had some request regarding to the stealth. Main questions were how Serbs were able to detect it, how to track it, was there any modification of the systems and also the capacity of the air defence system in detecting the stealth platforms. This

question is interesting because the controversy of B-2 for which Serbian side claim that was detected, fired upon and damaged and the airplane crashed in the Croatian side. There are many indications, confirmed by the intelligence reports but not material evidence provided at the time of this book is written. For details about the B-2 please see the previous section.

Russian officials admitted in 2001 that they used remains from the U.S. Air Force stealth fighter shot down over Yugoslavia to improve the ability of their air defense systems to detect and kill stealth aircraft. Also as part of the effort, designers say a small number of Russian tactical aircraft have been upgraded with locally produced, low-observable modifications to further test and improve their surface-to-air missile designs.

Acknowledging that researchers had access to the remains of the F-117 a senior Russian aerospace official said that they were able to test their system against the broken pieces. They didn’t found the Rosetta stone to unlock the stealth from the broken parts but despite that it was still a great asset for the reverse engineering and all kind of analyses. Of course, Russian will never say what information they were able to get and maybe even try to mislead and downsize what they really “recover”. The fact is that anti-stealth radars were rapidly developed after. The early Nebo VHF radar at MAKS in 2001 was the ancestor of the huge active electronically scanned array that was shown in 2013. Stealth modifications to tactical aircraft were confirmed a couple of years later when engineers from Moscow's Institute for Theoretical and Applied Electromagnetics spoke at a London conference about radar cross-section (RCS) reduction work on the Sukhoi Su-27 family.

Russian Defense Ministry's 2nd Central Scientific & Research Institute (2 TzNII) and its facilities, located in the city of Tver, performed all testing RCS models of the F-117 and many other aircraft. Parts of F-117A are on internal exhibitions halls in that institute. The same research led to the development of the Sukhoi Su-57, first Russian stealth airplane.

China has a history of being accused of stealing military aircraft technology. Croatian intelligence service and the admiral who was Croatia's chief of staff during the Kosovo War (admiral Domazet-Loso) said he believes that China formulated the technology for its J-20 jet from an American F-117A stealth fighter. This was based on reports which Croatian intelligence service gathers about Chinese activities in the area where F-117A fell.

Bombing of Chinese embassy in Belgrade and hangars at the Belgrade civilian airport during the NATO aggression where parts of F-117A allegedly were stored, may be considered as a deliberate warning to the Chinese side not to “try to remove” airplane parts. Of course, NATO will never acknowledge that but some indication leaning in that direction.

Manipulations started immediately after the aircraft was downed. It first started with the NATO press conference under the PR Jamie Shein. NATO PR stated that the video clips and photos in the Serbian TV were just one more game which Serbian propaganda played…Than it was announced that the aircraft crashed because the technical malfunction and in the third attempt it was confirmed that the airplane was hit and downed. We already discussed this issue in the previous chapters. The next new thing was that the NATO intentionally misled the public because it tried to "buy the time" while the rescue operation was underway. It was also questionable why the smoldering wreck was not bombed the same night and simply obliterated.

On the Serbian side, after the initial euphoria and jubilant celebrations some individuals started to play their own games. We already spoke about the work of the combat missile crew, duties and procedures. Missile crew is the team and as a team they function and complete their mission or they fail. Every team member is important, from the commander to the manual drawing board operator. The success is not contribution of just one member but the failure may happened if one individual not performs as expected. The missile combat crew is expected to do their duty…nothing less and nothing more. The crew is professional and lifelong devoted to their job. We can say freely that years of training and exercises achieved the culmination in those 25-27 seconds necessary to acquire the target, performs all procedural steps and hit the target. There is no a single individual who can say that he achieved that only by himself.

Unfortunately, from one extraordinary event the seed of division was planted. Lt. Col. Dani as a battalion commander started to behave and act like he was the one who downed the stealth. Immediately after the downing he was promoted with few other crew members but these promotions were not distributed equally among the combat crew. The brigade HQ and the air defence directorate and high command by humble opinion of one of the authors, didn't adequately rewarded all participants. One of the foggy explanations from the brass was that there are no service regulations in which everybody and everyone must be rewarded. As people are just people, this created tension within the

battalion but fortunately for all members, it did not negatively affected the unit performance and, as we saw in the previous chapters, the battalion had more successful engagements.

What really happened and put the dark shadow on the whole event, was that now Col. Dani started, as the most exposed battalion member, to speak more and more about his individual achievements glorifying his own role and grabbing the battalion glory for himself. This created the further tear between the rest of the crew and him.

The key players in the whole events retired few years after. Some others crew members stayed with the military and at the time of this book writing, they are still there.

It is worth to say this time that after the war the 3rd battalion ceased to exist as a unit and the whole 250th brigade was reorganized merging few remaining SA-3 battalions with survived equipment with SA-6 battalions forming the new formation which bear the same designation.

Col. Dani retired 2004 and started his own business as a baker in his village. Lt. Col. Anicic retired on his own request after the military couldn't find the position which is adequate to his rank and achievements and he was posted to the few ranks lower position. He then decided to write a book which is reflection of day by day diary that he wrote during the war. In this war diary, which is actually officially classified as a military document - combat diary of the battalion, he wrote about all events and his observations during the war. His observations and comments about the battalion actions, performances, strengths and weaknesses and also comments and observations about the higher command and individuals for sure didn't fit into the overall situation and performances after the war. he was virtually outcaste as a "black sheep". In his own word, he couldn't wait the time to be discharged from the military. That was the consequence of the stress and strain imposed on him.

Figure 8-45 Maj. Dotlic crew on duty (Source: "Smena")

Figure 8-46: F-16CG on Aviano tarmac (Source: USAF)

Figure 8-47 David Goldfein (Source: USAF)

Figure 8-48: F-16 CG jet engine (Source: RTS)

Figure 8-49: Lt. Col. Goldfein flight equipment (Source: RTS)

Figure 8-50: Hammer 34 tail in Belgrade museum (Source: Authors)

Figure 8-51: CSAR team which rescued Lt. Col. Goldfein (Source: USAF)

Figure 8-52: Praga with R-60 air-to-air missile installed (Source: Authors)

Figure 8-53: High elevation, ready for launch (Source: Authors)

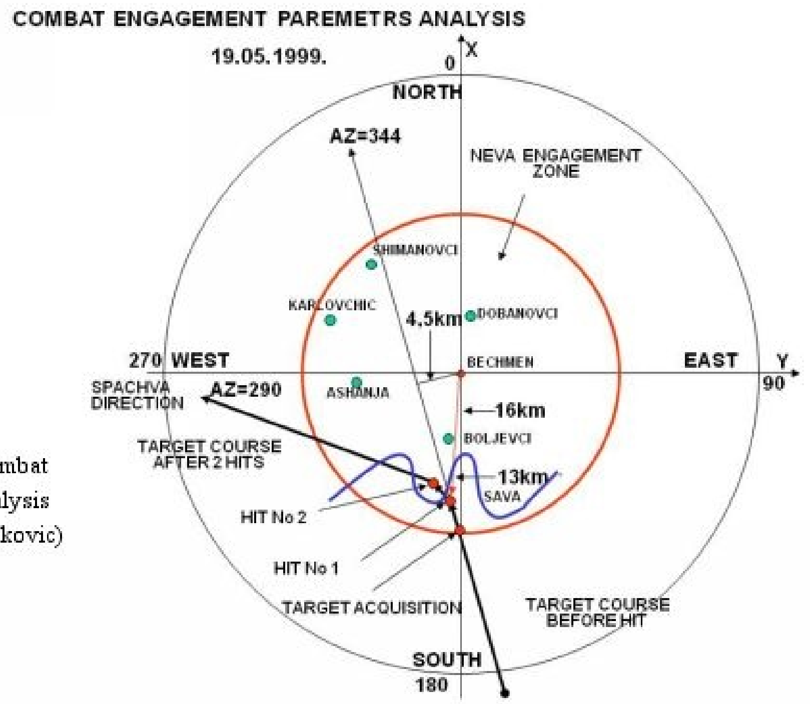


Figure 8-54: Combat engagement analysis (Source: V. Neskovic)

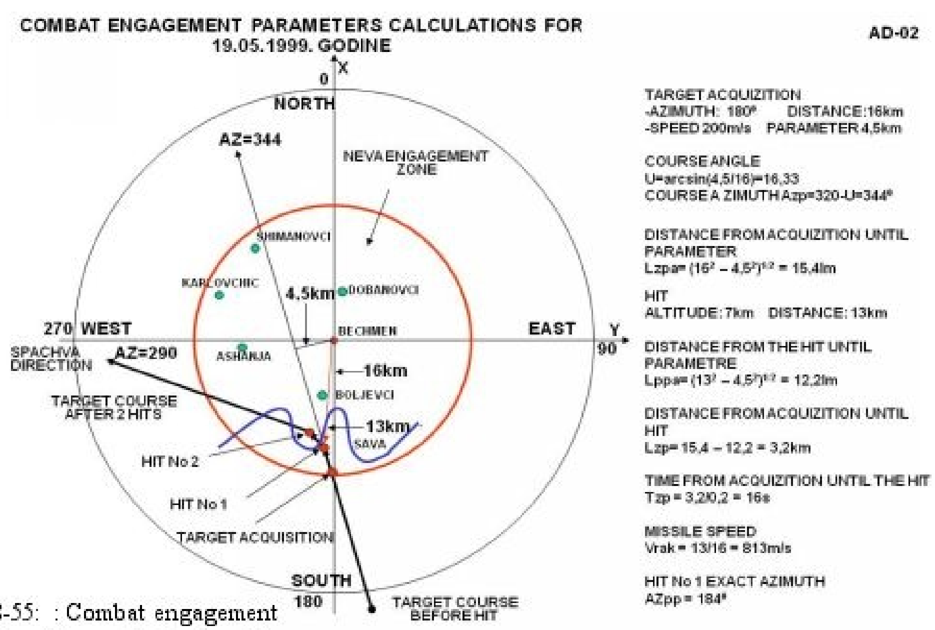


Figure 8-55: : Combat engagement calculation (Source: V. Neskovic)

Figure 8-56: Kill marks on UNK cabin door. (Source: Authors)

1. **Колико су били важни визуелни осматрачи на терену за Ф-117 и за Б-2?**

Битно је нагласити за визуелно извиђање да су авиони углавном коришћени ноћу, а Б-2 и на врло великим висинама, те није видљив визуелним осматрачима.

2. **Путање сипања горива за Б-2 – где је сипано гориво? Б-2 користи много другачији начин сипања горива од Ф-117. Да ли сте могли распознавати понашање Ф-117 од понашања Б-2 ?.**

3. **Основно питање за Б-2 је.Да ли сте препознавали овај авион при прелету преко ваше зоне?.**

Према нашим сазнањима Б2 је полетао из базе Вајтман из САД у пратњи обезбеђења ловачке заштите пуњења у ваздуху. Летео је на висинама преко 40.000 фита, чиме је могао избећи дејство ПВО. Како смо га ми откривали, слушали... Као и сваки авион мора да се пријави некој контроли летења када долази у тај реон. Имао је специфичне позивне знаке, изванредно јаку радио-станицу и летео је искључиво ноћу. Пријављивао се контроли летења Бриндизи. Долетао је са севера и дејствовао северно од 45 паралеле у рејону Београда, по унапред задатим специфичним циљевима: кинеска амбасада, зграда Муп-а, зграда МО. Регистровано је више од 10 авионолета.

4. **Да ли можете пратити тај авион? Да ли можете идентификовати тај авион?**

Можемо пратити циљеве до 18.000 метара те можемо идентификовати и овај авион.

Figure 8-57: Translated US questions. (Source: Authors)

Figure 8-58: Alleged crash site. (Source: Yandeks)

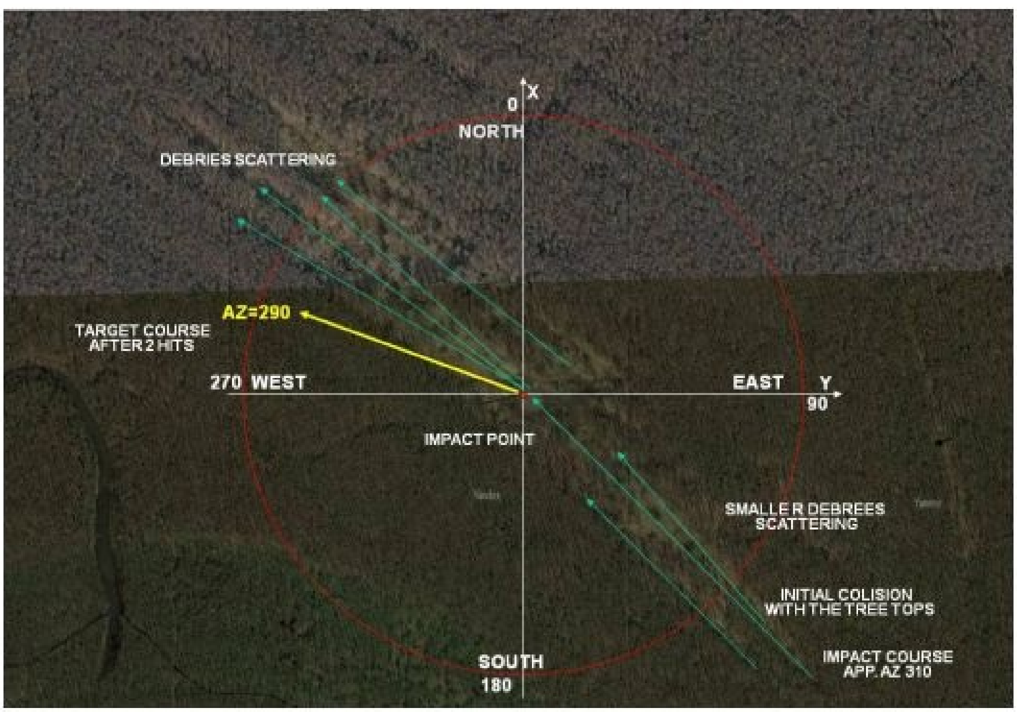


Figure 8-59: Impact angles. Note the similarity with the target departure azimuth after the engagement. at the Figures 8-58 and 8-59. (Source: Authors)

Chapter Nine

Aftermath

The Yugoslav Integrated Air Defence System (IADS) survived the NATO air campaign used to force the removal of Serbian forces from Kosovo, which ran from March 24 to June 9, 1999, and at its height involved over 1,000 aircraft. Survival of the IADS was achieved by employing three different methods to negate NATO's air power. NATO decision not to use ground forces certainly made Serb defensive measures much easier. By deliberately not employing all their defence assets at once, known as the strategy of withholding military force, the constant moving about of its mobile surface-to-air missile to ensure they could not be targeted, and the widespread use of deception measures.

The strategy of withholding military force is different to a holding action, as it is an asymmetric strategy for a weaker force to withstand attacks upon its centre of gravity, was developed by the Communist Chinese to nullify the overwhelming air supremacy that the United States and its allies held in Korea. By withholding forces from action, in the event of attacks by superior forces, it can absorb more punishment than otherwise, which Mao referred to as "the breaking of pots and pans".

The strategy is particularly important in the context of air power, as by hiding resources and deliberately withholding them from action, the forces trying to locate them cannot destroy them. An air campaign can then become one of virtual attrition to the detriment of the aggressor, due to the wearing out of men and machines, for very little gain. Morale and public opinion aspects also come into play when there appears to be little or no results for the resources expended.

A defending ground force needs to be forced to expose itself, thus allowing it to be attacked by air power. One option is to stage an attack that is designed to compel a defending force to react. An example could be the insertion of forces by air to embarrass the leadership into defending more areas. To enable air power to hunt down and then destroy targets requires robust Intelligence, Surveillance and Reconnaissance (ISR) systems and Precision Guided Munitions (PGM). Terrain masking and deception measures by small forces in complex terrain, such as hilly and/or jungle terrain, as occurred in Kosovo and in the various conflicts in Southeast Asia, often negate the use of most ISR systems, presenting difficulties in locating and positively identifying targets. The locating,

tracking and targeting of difficult to find targets often require quantities and technological capabilities of equipment beyond a country’s material resources.

The aim of the “Operation Allied Force” campaign was to force Serbian forces to “stop attacks” upon ethnic Albanians and leave Kosovo through the coercive application of air power alone. Air power was to be used, exclusively, to reduce casualties on the NATO side, which made life for the Serbian forces in Kosovo easier as there were no ground troops to worry about. By employing the strategy of withholding military force the Serbs avoided having their air defence and field units being destroyed in the first days of the air campaign. They had absorbed the lessons of Operation Desert Storm, and preserved their assets for the long haul, which was a successful strategy as Serb forces were still firing Surface-to-Air Missiles (SAM) on the last day of Operation Allied Force. Employing passive systems such as electro-optical tracking equipment further enhanced the survivability of IADS components, by not creating an emission signature that NATO defence suppression aircraft could lock on to.

Bad weather and the rigid insistence on avoiding collateral damage and casualties to the attack force dogged NATO planners. This led to an over-reliance on Precision Guided Munitions (PGMs). In the first three weeks of ‘Allied Force’ there were only seven days of "favourable weather" for air operations and ten days on which 50 percent of the strikes had to be cancelled due to the fear of collateral damage. Ninety percent of the ordnance dropped were PGMs which also had their own problems. Global Positioning System (GPS) aided munitions, the only affordable all-weather munitions, can be inaccurate due to the cumulative effect of numerous GPS errors, as well as small inaccuracies in the targeting aircraft, maps and the munition itself. This is called the ‘sensor-to-shooter error budget’ in United States parlance. Further, the amount of cloud over Kosovo caused many laser-guided bombs (LGBs) to ‘lose lock’ and ‘go rogue’ often landing kilometres away from their intended target.

The reliance on GPS guided bombs caused a shortage that became so acute in late April that the GPS guided Joint Direct Attack Munitions (JDAM) were available for only the B-2A Spirit bomber. By late April the ratio of PGMs to unguided munitions used had dropped to 69 percent. Many of the targets struck by PGMs in Kosovo were not judged to be worth the then $US12,000 cost of the Paveway II LGB kits, and could have been hit safely by unguided ordnance. The fire control avionics fitted to most NATO aircraft enabled very accurate bombing using ‘dumb’ bombs, albeit with a necessary reduction in

bombing altitude.

Serbian ground forces were hard to locate due to their small unit size and movement, generally being company sized units of between 80 to 150 personnel, and around six armoured vehicles, operating autonomously or semi-autonomously of each other. Using the woods and mountains, and by not being a large target or moving in a set direction, did not allow an intelligence picture to be easily built up, and thus made these forces difficult to locate from the air.

NATO's insistence upon avoiding collateral damage at all costs by using precision guided munitions, and the Serbian operational doctrine of hiding their forces, impacted the outcome. The resulting effect of these two strategies was “virtual attrition”, through the cost of the munitions expended and the accrued wear and tear on the employed aircraft.

The air campaign over Kosovo severely affected the readiness rates of the United States Air Force’s Air Combat Command during that period. Units in the United States were the most badly affected, as they were were stripped of their personnel and spare parts to support ACC (Air Combat Command) and AMC (Air Mobility Command) units involved in Operation Allied Force. The Commander of the USAF’s Air Combat Command, General Richard E Hawley, outlined this in a speech to reporters on April 29th, 1999. Further, many aircraft will have to be replaced earlier than previously planned, as their planned fatigue life was prematurely expended. PGM inventories needed to be re-stocked, the warstock of the AGM-86C Conventional Air-Launched Cruise Missile dropping to 100 or fewer rounds. Of the more than 25,000 bombs and missiles expended, nearly 8,500 were PGMs, with the replacement cost estimated at $US1.3 billion. Thus the USAF suffered from virtual attrition of its air force without having scored a large number of kills in theatre. Even if the United States' best estimates of Serbian casualties are used, the Serbians left Kosovo with a large part of their armoured forces intact.

Successful Deception Measures

Sun Tzu wrote that all warfare is based on deception and Serbian deception measures were very successful. Decoys were a real problem for strike aircraft, as loitering over an area at low altitudes made them targets for MANPADS, infrared guided point defence SAMs such as the SA-9 Gaskin and SA-13

Gopher, and SPAAGs such as the BOV-3/30 series and the Praga M53/59.

Hundreds of decoys were hit that were thought to be real targets. Some of decoys were also deliberately hit multiple times, so pilots would not loiter over them trying to discriminate between them and real targets. They also used up valuable airframe hours, and the incurred attendant increased logistical costs. Air forces have not always had invested sufficiently in sensors to counter deception and camouflage techniques, which the Serbs exploited quite successfully. This was noted quite early in the post Allied Force after-action study (**Figure 9-5**).

NATO flew approximately 30,000 sorties during the war, and just under 2,000 of these saw ordnances expended. These sorties were claimed at the time to have destroyed 93 tanks and 153 armoured personnel carriers (APCs) out of the approximately 350 tanks and 440 APCs believed to have been in Kosovo. NATO also claimed to have hit 339 military vehicles and 389 artillery pieces and mortars. These figures were widely off the mark as General Clark, the Operation Allied Force commander, conceded that not all targets hit were destroyed, and that only 26 vehicles could be confirmed as kills.

Their techniques included constructing false bridges, fake artillery pieces made of long telephone poles painted black with old truck wheels, antiaircraft missile launchers constructed of old milk cartons, and wooden mock-ups of MIG-29 aircraft, self-propelled artillery vehicles constructed on old vehicle shells and chassis, radar reflectors (developed by one of the authors) around the real military equipment, extensive use of camouflage nets etc.

In particular, radar imitators played a crucial role in the survival of the missile battalions. As we saw in the previous chapters, the innovative use of radar imitators by Lt. Col. Anicic, greatly contributed to the successful countering NATO hunter-killer groups and even in the events of multiple attacks from the different directions, combat engagement of the imitator in cooperation with the fire control radar emission successfully defended the missile battalion under attack.

Fixed Air Defences Crippled but Mobile Air Defences Survived

NATO air planners were certainly concerned that not as many Serbian SAM batteries were destroyed, as they would have liked, with the then commander of the United States Air Forces in Europe (USAFE) acknowledging the success of Serbian SAM battery shoot-and-scoot operational tactics. Mobile systems suffered few casualties, but the fixed defences were badly damaged. Two of Serbia's three static S-75 Dvina / SA-2 Guideline SAM battalions and 70 percent of their static S-125 Neva / SA-3 Goa SAM sites were hit and majority completely destroyed. Some of the system were damaged but repaired after. Only three mobile 9M9 Kvadrat/SA-6 Gainful SAM systems were hit and damaged (**Figure 9-3**, **Figure 9-4**).

Serbia certainly left Kosovo and suffered a tremendous amount of damage to its infrastructure in Serbia, yet in the face of an air campaign that at the end numbered over 1,000 aircraft, Serbian combat power remained substantially intact. The number of sorties generated by the NATO forces, particularly the United States Air Force, left them short of spare parts and munitions, required increased maintenance, and a force reduced in effective size due to the decreased fatigue life of many aircraft. This virtual attrition, with little relative destruction of the opposing forces, has shown that the Serbian military strategy was successful, even if the president Milosovic regime did not achieve its political objectives.

A total of 815 SAMs were fired at NATO aircraft, of which 665 were radar guided SA-3 and SA-6 rounds. One F-16C and one F-117A were killed by SAM shots and fell inside Serbian territory. There are at least 3 other airplanes including two F-117A, one Harrier, one F-16 and one A-10 suffered some kind of damage from a hit or near miss. Many SAM shots were unguided due to the radar shutting down to avoid HARM shots (**Figure 9-1**). NATO expended a total of 743 AGM-88 HARM anti-radiation missile rounds, launched by EA-6B Prowlers, F-16CJ Weasels and Tornado ECRs. (**Figure 9-2**).

The strategy of withholding military force in Kosovo was a military success, even if it did not prevent a political failure. Serbia retained its ground combat strength, in the face of overwhelming air power, and the Kosovo Liberation

Army was disarmed as part of the political settlement.

The first key lesson on the NATO side for the campaign produced, was that an opposing ground force must be driven out from cover, to induce the concentration of force required to facilitate efficient targeting and destruction by firepower. The need to keep NATO casualties to an absolute minimum was the reason for the decision not to deploy ground forces, but as shown earlier in this paper, this reduced the effectiveness of the air campaign. The Serbian forces used their freedom of movement to maximum advantage.

The second key lesson of the war was the effectiveness of the passive air defence measures, especially mobility and decoys, on the air campaign itself. A NATO squadron commander, who reviewed the original 1999 version of this paper, said the paper should emphasise decoys more as they were a huge problem during the campaign. This was explored in the second section of the paper, but the discussion was limited by the open source material available at that time.

The Russian military certainly took notice of Operation Allied Force and this is reflected in fundamental doctrinal and technological changes in their approach to operating and designing air defence systems.

There is much new equipment, primarily of Russian and Chinese origin, but also from Belarus and the Ukraine, now available on the open market as building blocks, for any country with enough money and the motivation, to create a highly survivable Integrated Air Defence System.

F-117A Retirement and beyond

F-117 went into the "retirement" in 2008. The most common explanation why F-117A was withdrawn from the service is introduction of F-22 Raptors. According to the US Air Force, when the Nighthawk was retired, it was mandated that the jet be kept in “Type 1000” storage. Aircraft in Type 1000 storage are to be maintained until recalled to active service, should the need arise. Type 1000 aircraft are termed inviolate; meaning they have a high potential to return to flying status and no parts may be removed from them. These aircraft are “re-preserved” every four years. Also, it can take 30-120 days depending upon how long the aircraft has been in Type 1000 storage for it to become flyable again.

Since its retirement from active flying status in 2008, the Air Force’s cadre of F-117 Nighthawks have been maintained at their original, climate-friendly hangars at the Tonopah Test Range Airport in Nevada. Given the cost of establishing secure storage facilities at Aircraft Maintenance and Regeneration Center (AMARC at Davis-Monthan AFB), the Air Force chose instead to store the retired F-117s at the pre-existing secure facilities at Tonopah Test Range.

Per Congressional direction within the FY07 National Defense Authorization Act the aircraft were placed in Type 1000, flyable storage for potential recall to future service. In order to confirm the effectiveness of the flyable storage program, some F-117 aircraft are occasionally flown.

It was originally stated that the entire F-117A fleet, minus one pre-production example which was scrapped (**Figure 9-11**) as an experiment at Plant 42 in Palmdale, CA, would be put into regenerative storage at the F-117′s original operational home, desolate Tonopah Test Range Air Base in south central Nevada. The stored aircraft's systems would be "mummified" and their wings would be removed so that up to five aircraft could fit into a single hangar which once housed two of the jets during their early operational heyday. Although there were murmurs about a handful of F-117s being kept in flying condition, the USAF has not addressed exactly how many of the black jets would be kept in such a state, and more importantly, why they would be kept in a flyable condition in the first place.

Since the F-117 officially stopped flying, the black jet has been spotted on numerous occasions. Keeping even a small force of F-117s flying is not a cheap or easy task. As the program's active operational talent retires, or migrates deeper into other aerospace programs, the "brain-drain" pertaining to such a unique weapons system would represent serious challenges.

Also, the Nighthawks were unique and temperamental aircraft and required a comprehensive logistical train to keep them in the air. Keeping just a handful of these jets flying would be costly and not without risk. In order to do so the USAF, or Lockheed Martin, would have to keep pilots current without the simulators and large training regimens that once existed for the aircraft. Furthermore, knowledgeable maintenance personnel would have to keep these aircraft in the air and their temperamental radar absorbent material, which is somewhat archaic by today's standards, would need constant care.

There were some speculations how F-77 may be utilized, if any. As a unique aircraft, the F-117 could be theoretically used as something of a "flying measuring platform" for evaluating a radar system's ability to detect and track low-observable flying objects. Or conversely, it could be used as a surrogate to test new radar absorbent materials and coatings applied to its flat, facet like structure that was originally built to accept such applications.

By specifically utilizing the F-117 for such-real life tests and evaluations, defense program managers could have a control variable, in this case the F-117′s well documented radar cross-section, infrared and visual signature, and an independent variable for which to test upon it. That independent variable being an experimental radar absorbent material or other signature control application.

Testers of new signature control applications, such as an innovative new version of radar absorbent material (RAM), could leverage highly accurate real-life metrics and historical data collected throughout the life and development of the F-117. They can then fly their new application on the jet so that new data can be collected for which to compare and help judge the effectiveness of the experimental capability being tested.

On the radar and infrared tracking side of argument, the F-117 is also a near-perfect and highly available low observable aircraft to test everything from ground-based radars and SAM systems, both foreign and domestic, AWACS modifications, fighter radars and even infrared search and track systems.

By doing so, testers can come up with a clear idea of what the capabilities of the system being tested are against a hard to detect target. In doing so, tacticians can work on solutions for defeating any weaknesses in the system while at the same time working on emphasizing its unique strengths. Even keeping a couple "sterile" F-117s available for calibrating and improving the DYCOMS array at Groom Lake, used for measuring the radar cross sections of aircraft flying under real world conditions, may be in itself an entirely necessary and worthwhile reason to keep a small cadre of F-117s operational.

Under certain circumstances the F-117 fleet could have even been turned into an even more potent and employable "silver-bullet" attack force by removing the pilot from the equation. Also, seeing as one F-117 had already been lost to enemy forces during Operation Allied Force over Serbia, and its wreckage evaluated by America's military technology competitors, the technological risk of using such a modified platform in future conflict seems negligible. In fact, it would probably be much lower than using a new unmanned combat air vehicle (UCAV) that features the latest in stealth, sensor and automated technologies.

Although there are no indications that the Nighthawk fleet was modified for such use it is possible that the small handful or the aircraft seen flying today are experimenting with such a conversion. Even if such a modification was not intended specifically for the F-117 fleet, its advanced autopilot and navigational suite would most likely make such a "man out of the loop" conversion easier to test than in a more conventional surplus fighter aircraft. Maybe even a crude version of such a conversion has been developed and tested and could be implemented on the remaining mothballed Nighthawk fleet during a time of war against an enemy with an advanced integrated air defense system.

The F-117 is the only disclosed surplus operational stealth aircraft in America's inventory. That being said, the world's armed forces probably have a pretty good idea of its true stealth capabilities after decades of operations around the globe, its participation in many international exercises and the proliferation of low observability design knowledge in the decades since it entered service. This is not to mention the undoubtedly countless espionage operations conducted by America's enemies and allies alike regarding the F-117's unique technologies.

The rest of the world is increasingly catching up to US once exclusive monopoly on "stealth" technology. Fighters such as the Russian Sukhoi Su-57 and the Chinese Chengdu J-20 are well on their way to becoming potential

challengers to American and allied air supremacy. Furthermore, stealthy unmanned aerial vehicles and cruise missiles are even easier to develop than their manned counterparts. So, it would make sense for the United States and other allied nations to begin training against low observable adversary aircraft, especially in the realm of detecting, intercepting and engaging them. With all of this in mind, it would make total sense for the USAF to field the F-117s as stealth aggressors.

Having a small aggressor force of F-117s available for putting our, and our allies' latest radars, infrared search and track and electronic detection system to the test, as well as to develop tactics for defeating such threats, seems like a perfect job for the F-117. Seeing as the F-117 is a largely declassified program, the technological risk of standing up such a unit and employing it even in training with our allies would be negligible. F-117 aggressor duties could also be of great value when paired with advanced electronic warfare and jamming. In other words, combining other tactics aside from the aircraft's inherent stealthy design could still make for a world class low observable opponent or target even though the aircraft itself is well over 30 years old.

As non-American stealth platforms hit the skies operationally around the world, the US is going to have to begin fielding some sort of low observable aggressor aircraft for large air warfare exercises. Red Flag, the largest aerial war-game of it kind, just so happens to take place right where the remaining F-117s are based, either at Tonopah Test Range Air Base, or at Groom Lake, otherwise known as Area 51.

By April 2016, lawmakers appeared ready to "remove the requirement that certain F-117 aircraft be maintained in a condition that would allow recall of those aircraft to future service", which would move them from storage to the aerospace maintenance and regeneration yard in Arizona to be scavenged for hard-to-find parts, or completely disassembled.

On 11 September 2017, it was reported that in accordance with the National Defense Authorization Act for Fiscal Year 2017, signed into law on 23 December 2016, "the Air Force will remove four F-117s every year to fully divest them - a process known as demilitarizing aircraft". As a time of writing of this book, this is still in force.

On the other hand, SAM-3 is still in use in many countries worldwide. As we saw in the Chapter S-125, numerous upgrades are available. Since Russia replaced all of its S-125 sites with SA-10 and SA-12 systems, they decided to upgrade the S-125 systems being removed from service to make them more

attractive to export customers.

Released in 2000, the Pechora-2 version features better range, multiple target engagement ability and a higher probability of kill (PK). The launcher is moved onto a truck allowing much shorter relocation times. It is also possible to fire the Pechora-2M system against cruise missiles. Deployment time 25 minutes, protected from the active interference, and anti-radiation missiles (total in practical shooting).

Early warning radar is replaced by anti-stealth radar Caste 2e2. Target acquisition distance at 2.5–32 km and altitude range - 0.02–20 km. with the maximum speed of 1000 m/s. Missile launchers can be positioned at up to 10 kilometers away from the control center. The upgraded system uses 5V27DE rocket with increased range of splinters. target hit probability with the first missile at a distance up to 25 km is 0,72-0,99%. Detection range of the target with the radar cross section of 2 m^2 is about 100 km. target with RCS of 0.15 m^2 is about 50 km, with no interference. When operating in the EW saturated area and targets using active jamming detection distance is 40 km. ADMS "Pechora-2M" has the ability to interfacing with higher level command post and radar remote using telecode channels. It is equally effective at any time during the day and at night (optical location, daytime and night time, and also thermal imager (up to 30 km of night and 60 km of day), for such a system, the detection range of an aircraft such as F-16 is 30 km away.

In 1999, a Russian-Belarusian financial-industrial consortium called Oboronitelnye Sistemy (Defense Systems) was awarded a contract to overhaul Egypt's S-125 SAM system. These refurbished weapons have been reintroduced as the S-125 Pechora 2M (**Figure 9-6**, **Figure 9-10**).

In 2001, Poland began offering an upgrade to the S-125 known as the Newa SC (**Figure 9-7**, **Figure 9-8**). This replaced many analogue components with digital ones for improved reliability and accuracy. This upgrade also involves mounting the missile launcher on a WZT-1 tank chassis, greatly improving mobility and also adds IFF capability and data links. Radar is mounted on an 8-wheeled heavy truck chassis (formerly used for Scud launchers).

Serbian modifications include terminal/camera homing from radar base and digital displays.

Cuba also developed a similar upgrade to the Polish one, mounted on T-55 chassis, which was displayed in La Habana in 2006 (**Figure 9-9**).

Later the same year, the Russian version was upgraded again to the Pechora-M which upgraded almost all aspects of the system - the rocket motor, radar, guidance, warhead, fuse and electronics. There is an added laser/infra-

red tracking device to allow launching of missiles without the use of the radar.

There is also a version of the S-125 available from Russia with the warhead replaced with telemetry instrumentation, for use as target drones.

In October 2010, Ukrainian Aerotechnica announced a modernized version of S-125 named S-125-2D Pechora. As of 2018 according to the UkrOboronProm, the S-125 surface-to-air missile underwent an integrated modification of all elements, including modernization of missiles, as well as the use of a new radar station built on solid-state elements.

It is obvious that the SAM-3 passed through a rebirth and for the years to come it will be still in use with constant modifications and upgrades.

Future of SAM vs Stealth

We already discussed some implication of the first stealth downing in combat. Both sides in the conflict learned hard lesson. Tactics and procedures for the attackers were improved; counter stealth measures for the defenders were also improved. Some of the previous manuals are rewritten and corrected. From this distance, SAM-3 has been improved with the new technical developments and solutions which injected a new life into the old-timer, so it will serve well into the 21st. century. F-117A, now officially retired (since 2008) was a revolutionary airplane which push the boundaries of the aerodynamics and stealth into the new areas. New stealth airplanes were developed, and they are and they will be involved in the conflicts and wars to come. Also, air defence evolved and there are constant improvements with the new systems introduced and implemented. This is never ending process. Every measure creates a countermeasure.

There are three major fields where those technologies clash:

- Stealth aircraft
- Counter stealth detection and tracking
- Air defence missile

Stealth Aircraft

The F-117A, B-2 and B1-B can be regarded as the three emblematic low observability aircraft of the late '80s. Having realized the capabilities offered by low observability technology, the U.S. went on developing a number of stealth jet fighters, such as F-22A Raptor (first flight in 1997, production ended in 2011, with 195 planes built). Lockheed Martin (L.M.) was the prime contractor and Boeing the main partner (**Figure 9-12**).

The Locked Martin F-35 Lightning II (**Figure 9-13**), a multirole 5th gen. fighter with stealth capabilities (first flight in 2006, currently in production). There are three variants, the F-35A CTOL (Conventional Take-Off and Landing), the F-35B STOVL (Short-Take Off and Vertical-Landing) and the F-35C CV (Carrier Variant). The F-35 is based on the Joint Strike Fighter (JSF) program, which started in the mid '90s. In 2001 the L.M. X-35 won the JSF competition

over the Boeing X-32. Consequently, L.M. was awarded the System Development and Demonstration contract, to develop the F-35, based on X-35. The development of the F-35 is funded primarily by the U.S. and by several other partner-nations, at varying levels. F-35 first foreign buyer was Israel.

It is claimed that the F-35 fuselage design, as a result of a trade-off between cost and requirements, did not follow the “standard way”, as in F-117 or the B-2. For the F-35, the approach was the construction of a l.o. aircraft, taking seriously into account the cost parameter. Therefore, in the frame of cost reduction, some capabilities were “sacrificed”: RCS is really low in the X-band (8 – 12 GHz) and in the Ku-band (12 – 18 GHz), while it is not so low at lower frequency bands. The scope is the break of the killing chain: even if the F-35 is detected by surveillance radar, it may not be easy to be engaged by a fire control radar, which usually operate in the X or Ku bands. On the other hand, the F-22 presents a lower RCS from all aspects and at more frequency bands, of course at a considerably higher cost.

The serial production F-35 is expected to present a bit higher RCS than the prototype X-35, since more volume was required for the internal equipment and armament bays. The curves of the redesigned fuselage will incur an RCS increase, from some certain directions. It was calculated that the RCS will remain very low from the frontal sector and more precisely from a sector of 29º in front of the aircraft. However, the RCS will not be so low from the lateral aspect and also from the rear aspect. The whole behavior deteriorates at lower frequency bands. The researchers of the Air Power Australia created a 3-D model of the underside of the fuselage and tried to calculate the RCS, using the POFACETS algorithm, developed at the Naval Postgraduate School of the USN, proving in this way their arguments.

In any case, there are no doubts that the F-35 will exhibit stealth capabilities, maybe not as good as the F-22 but most probably better than any other aircraft. In order to estimate the maximum detection range for the F-35, first there should be an estimation of the F-35 RCS, and then a calculation, using the radar equation and the logic mentioned before, with respect to the detection range for a standard target used for comparison purposes. As a “standard target” for the comparison, a 1 m^2 RCS target will be used. A target of 1 m^2 RCS corresponds to a small fighter, such as the Northrop T-38 Talon.

The detection range for a search radar 64N6E of the S-300 PMU-1 system

(Almaz - Antey), operating in the S-band, with a maximum range of 300 km (162 NM), for a 1 m² RCS target is calculated to be 110 nautical miles. Engagement radar 30N6E1 of the same system operating in the X-band, with a maximum range of 150 km (81 NM) the detection range for the “standard target” is 55 NM.

Boeing proposed a low observability variant of its proven fighter F-15E, designated as F-15SE Silent Eagle. Initially, Boeing declared that the F-15SE would exhibit a l.o. level comparable to the one of a 5th gen. aircraft, implying the F-35. Boeing spokesman clarified that they meant that “the Silent Eagle could meet the level of stealth approved by the U.S. Government for release to international customers”, a point still reflected in their most recent description of F-15SE. Also, Boeing had extensively applied l.o. techniques on the F/A-18E/F Super Hornet. Furthermore, in August 2013, Boeing started flight-testing of the “Advanced Super Hornet”, a new variant of the F/A-18E/F Super Hornet, with conformal fuel tanks, an enclosed weapons pod and “signature enhancements” designed to substantially increase the range and reduce further the radar signature.

Russia developing their stealth program designated as PAK FA which is now renamed Su-57. The Sukhoi PAK FA is being developed by Sukhoi for the Russian Air Force. Its prototype, T-50, flew for the first time in 2010. The PAK FA is a 5th gen., multirole, twin-engine jet fighter, which will replace a number of older Russian fighters. The expectation is that the PAK FA to reach the stealth levels of F-22 and outperform it in other aspects. Based on PAK FA, Sukhoi offered a partnership with HAL (Hindustan Aeronautics Limited), the “Fifth Generation Fighter Aircraft” (FGFA) for India but that didn’t materialize.

On 21st February 2018, two Su-57s were spotted landing at the Russian Khmeimim air base in Syria. The aircraft were deployed along with four Sukhoi Su-35 fighters, four Sukhoi Su-25s, and one Beriev A-50 AEW&C aircraft. Three days later two more Su-57s were reported to have arrived in Syria. According to the press the Su-57s have "excellently" carried out their mission in Eastern Ghouta. On 1 March 2018, the Russian Defence Minister confirmed that the two Su-57s indeed spent two days in Syria and successfully completed a trials program, including combat trials during which parameters of weapons work were monitored. On 25 May 2018, the Russian Defence Ministry revealed that during the February 2018 deployment to Syria, a Su-57 fired a Kh-59MK2 cruise missile in combat.

China is developing the Chengdu J-20 (first flight in 2011) and more recently the smaller Shenyang J-31 (first flight in 2012), both twin-engine. There are a lot of speculations in which Chinese used parts of downed F-117A to reverse engineering the structure and stealth coating which were implemented into their programs.

In Europe, l.o. techniques have been applied to Rafale (Dassault Aviation) and Eurofighter Typhoon (EADS), reducing drastically their radar signatures, even though technically they are not stealth aircraft. Rafale is supposed to employ also active techniques to hide from enemy radars, using its advanced countermeasures suite.

Among other efforts towards developing a l.o. aircraft, one should also mention TF-X, a 5th gen. fighter being developed by Turkish Aerospace Industries, in partnership with SAAB AB, according to Turkish press. First flight is scheduled for 2023. In the next decade, more than 250 TFX are expected to serve alongside the 100 F-35 which Turkey intends to procure.

Apart from manned aircraft, l.o. technology is applied to Unmanned Aerial Vehicles (UAV) as well. An indicative list would include the Boeing X-45, the BAE Systems Taranis, the Dassault "EURO" (Greece participates in this project), the EADS Barracuda, the L.M. RQ-170 Sentinel, the MiG Skat and the Northrop Grumman X-47B, which on 10-07-13 landed on an aircraft carrier at sea (for the first time for a UAV)

Counter-Stealth Radar Systems

The US approach to stealth has seen a combination of technologies employed, to produce the overall effect of “stealth”. Active emissions by aircraft radar and datalinks have been reduced by the adoption of what are termed ‘Low Probability of Intercept’ or LPI techniques. LPI techniques typically rely upon the use of very wideband frequency hopping techniques, noiselike waveform modulations and sometimes pseudorandom scan patterns, to made radar and datalink/network emissions very hard to detect. A modern AESA radar with the ability to hop across a Giga Hertz or more of bandwidth, using spread spectrum modulated pulse trains, will be all but invisible to the crystal video receiver technology radar threat warning systems of the late Cold War era. The radar signatures of aircraft and missiles present a much more challenging problem, for a variety of good reasons. The most prominent of these is that threat radars may

be operating across a range of wavelengths, from around ten meters down to less than a centimeter. This has important implications for the two primary technologies employed in producing VLO capability. The two primary technologies used in airframe radar cross section reduction are shaping and materials.

Materials are often touted as the solution by parties who do not understand the physics well for example “apply this magical coating and your aircraft will vanish off their screens”. The pragmatic reality is that coatings and materials are usually only effective over a fairly narrow band of frequencies, and often to get good effect, considerable depth or thickness is required, resulting in weight and volume penalties. Central to the difficulties with radar absorbent and lossy materials is the ‘skin effect’, where radio-frequency electrical currents induced by an impinging wave tend to concentrate in the surface of an object. With highly conductive materials like aluminum skins, this layer is extremely thin for most frequencies of interest, making such skins excellent reflectors. Absorbent or lossy coatings, however, must be much less conductive to produce effect, and this results in much greater skin depth. As a result, a very thin coating or laminate which might be highly effective against a 10 GHz radar is apt to be ineffective against a 10 MHz or 100 MHz radar as the skin depth becomes many millimeters or centimeters deep.

The most common approach to this problem is the use of radar absorbent structures, an example being the leading edge on the B-2A ‘batwing’ bomber, which has the depth to accommodate complex absorbent structures, which are highly effective over a very large bandwidth. This is a much more difficult problem for fighters, as volume and weight are much more critical problems. Airframe shaping is however where the biggest gains are to be had in making aircraft stealthy, in fact the rule of thumb is that the first one-hundred-fold reduction in radar signature is produced by smart airframe shaping, and the remaining ‘fuzzball’ of minor reflections is then soaked up by absorbent or lossy materials.

For example, a conventional fighter design might have a radar cross section of one square metre in the centimeter wavelength band, but an equivalent design with proper stealth shaping might be only 0.01 square metre, and further application of absorbent materials in the right places then drives that down to 0.001 to 0.0001 square metre.

The effectiveness of shaping is like the effectiveness of materials, dependent upon the wavelength of the threat radar. Where the flat area, facet or leading edge is much larger in dimensions than the wavelength of the radar, the rules of geometrical optics apply, and reflections can be very precisely bounced away from the threat radar. The aligned leading edges, aligned planforms and facets or flat areas seen in the F-117A, B-2A and F-22A are all extremely effective down to wavelengths of the order of tens of centimeters, or in the instance of the B-2A, down to metres. In frequency terms fighters are stealthiest in the X-band and S-band, while the B-2A is stealthy down to the VHF band.

Where the shaping features are comparable in dimensions to the wavelength of the radar, an effect called “resonance” occurs, resulting in the induced electrical charges in the skin of the target running back and forth and waves then reradiating from edges, tips, or other prominent shapes. For fighter sized aircraft the resonance region is primarily in the UHF frequency band. In this so termed “resonance scattering region”, it becomes very difficult to control the direction and shape of reflections. Some techniques using for instance resistive and magnetic materials along edges are often used, but in general fighter sized targets are no longer marble or golf ball sized reflectors.

This effect becomes increasingly exacerbated as the wavelength reaches a metre or more, where the radar signature becomes effectively proportional to the physical size of the reflecting feature. This is termed the “Raleigh scattering region”. VHF band radars which operate typically between three and one metre in wavelength occupy this region for typical fighter sized targets.

Historically, stealth designers have focused their effort in the centimeter and decimeter bands, since these are where most fire control, engagement, air intercept and missile battery acquisition radars operate. The aim of the stealth effort was thus to disrupt the ‘kill chain’ by denying opportunities to launch and guide missiles, or frustrating the missile seekers and thus disrupting terminal missile guidance.

If we look at operating bands for typical Soviet era missile battery engagement, guidance and illumination radars, we find the SA-2’s SNR-75 Fan Song in the upper S-band or lower X-band, the SA-3’s SNR-125 Low Blow in the X-band, the SA-4’s 1S32 Pat Hand in the X-band, the SA-5’s 5N62 Square Pair in the S-band, the SA-6’s 1S91 Straight Flush and the SA-8’s Land Roll radars in both the X- and S-bands, and finally the SA-10’s 30N6 Flap Lid and

SA-12’s 9S32 Grill Pan in the X-band.

Where a defender is reliant on search and acquisition radars operating in the S-band, examples including the widely used Soviet/Russian P-30 Big Mesh, P35/37 Bar Lock, P-30 Big Mesh, P-40 Long Track, 19Zh6/36D6 Tin Shield, 64N6 Big Bird, or US AN/ TPS-43 and AN/SPY-1 Aegis, then a byproduct of good stealth is surprise as beyond some detection range the stealth aircraft is invisible. Operators of Russian air defence equipment will be willing customers for upgrades to legacy systems that were considered ineffective against stealth aircraft. Upgrade packages are on offer for the VHF band P-14 Tall King and P-18 Spoon Rest D, the UHF band P-15/15M/19 Flat Face and Squat Eye, and customers can also purchase a range of new build VHF radars, including the 55Zh6-1 Nebo UE Tall Rack, the 5N84AE Oborona-14 Tall King, the 1L13-3 Nebo SV, the 1L119 Nebo SVU, and the Vostok E. The latter two are entirely new post Cold War designs. The trusty Flat Face / Squat Eye UHF radars remain in production in digital solid-state form, as the 39N6E Kasta 2E1 and 2E2. The Chinese have followed this trend and are actively marketing the JY-27 VHF radar, similar but larger than the 1L13 Nebo SV, and have displayed another smaller type which remains to be identified.

Many of the new Russian designs are phased arrays, and at least two of the VHF designs are active phased arrays (AESA) dispensing completely with all vacuum tube technology, and embedding Transmit Receive Modules (TRM) in the antenna subsystem. Typically, the computers and software used for digital signal and data processing in these radars are Commercial Off The Shelf (COTS), no differently than their Western counterparts, even using large LCD display panels. Russian literature claims the use of the latest Space Time Adaptive Processing (STAP) algorithms for clutter rejection, which given the known skills base in mathematics and physics in Russian research institutes, is a credible claim. If a Western manufacturer were asked to design a VHF radar, the technology and components it would be built from would be much the same.

Russia is leading the counter stealth development programs. Russian marketing literature and numerous interviews with chief designers or senior design engineers invariably focus down on the issue of counter-stealth capabilities in these radars. Key points, raised repeatedly in interviews are Raleigh and resonance mode scattering versus geometrical optics scattering and skin depth impairing the performance of radar absorbent coatings. These are precisely what radio frequency physics and the extensive unclassified US

engineering literature on stealth identify as key limitations. More than one Russian designer has publicly commented on the F-117A, famously known in the West as a "ball bearing sized target" in the S-band and X-band, as a "one half square metre" sized or beachball sized radar target in the VHF band. Likely this claim is the result of detailed scientific analysis of radar tapes from the Allied Force campaign. Russian and Byelo-Russian designers have claimed detection ranges of up to 180 nautical miles against fighter sized stealth aircraft, claims consistent with cited range specifications for these radars.

The flagship of the Russian counter-stealth radar effort is the digital 55Zh6M Nebo M radar (**Figure 9-14**, **Figure 9-15**) system. This design is a genuine three-dimensional Active Array radar System (AESA), with three individual networked radars on three separate high mobility BAZ-6909 8x8 vehicles, and a fourth vehicle which performs data fusion from the three radars, and target tracking. One radar operates in the VHF-band, one in the L-band, and one in the S or C-band. The VHF-band RLM-M radar is the largest mobile 3D VHF-band radar ever built anywhere. The design could accommodate configurations with different mixes of radars such as replacing the C or S-band RLM-S component with an L-band RLM-D or VHF band RLM-M. The use of networked data fusion permits this system to cue the RLM-S and RLM-D components to stealth targets detected initially by the RLM-M component.

The Nebo-M evolved in part from the earlier 1L117 Nebo SVU mobile VHF-band radar, at least one example of which was sold to Iran some years ago. The Nebo SVU included some sophisticated anti-jamming features. Curiously the Nebo-M's numerical designation is based on the very different 55Zh6UE Nebo U/UE Tall Rack, a gargantuan fixed 3D VHF-band radar with a characteristic and unique inverted T shaped antenna. These systems are supplemented by the Rezonans N/NE marketed by Rosoboronexport as a 'Stealth Air Target Early Warning Radar'. It is a large multistatic elocatable VHF-band radar system, carried on several vehicles. Technical disclosures have been scarce.

China's CETC/CPMIEC has also been very active in this area, following their earlier YJ-27 VHF-Band radar. The recently disclosed VHF-band HK-JM with cited 300 km range, and the HK-JM2 with cited 500 km range, are genuine mobile radars with integrated telescoping and elevating mast systems.

The third player in this market is Belarus, where KB Radar are selling the modern digital solid state Vostok D and E VHF-band radar, a high mobility

design which can stow and deploy in as little as 6 minutes, almost as quickly as a SAM battery. The Chinese HK-JM series is modelled in part on the Vostok series, but using older antenna technology than the innovative Belarus design.

Counter-Stealth Concepts

Counter-Stealth or Counter-Very Low Observable (CVLO) techniques encompass possible techniques that overcome the effects of stealth design methods. While many technologies and techniques have been proclaimed to be CVLO panaceas, closer examination suggests otherwise. Broadly, there are two approaches in overcoming a stealth design. One is the brute force approach of finding ways of making a sensor that is much more sensitive, able to find a much fainter target; the other is to build a sensor that can see the stealth design in some area in which it was not designed to be stealthy.

The brute force approach in radar design usually manifests in increasing the peak and average emitted microwave power the radar produces. This is usually not cheap, and often introduces other problems such as providing enough power to drive the radar, getting rid of waste heat from the radar, and making sure key components in the radar are not overstressed electrically or thermally. This is a commonly favoured approach in land based or naval radars, as the requirements can be challenging for compact airborne radars. Due to the inverse square law behaviour of radars, maintaining detection range against a target which reflects 1/100 of a conventional target requires a 100-fold increase in radar emitted power. While doubling or quadrupling power output in a radar may be feasible, increasing it tenfold or hundredfold usually is not.

Two techniques which can alter the radar’s ‘duty cycle’ are to increase the density of pulses the radar emits, and to increase its ‘dwell time’ or how long it spends looking in a given direction. The former inevitably increases the power requirement, while the latter increases search times. Since the aim of radars is to find and track targets, increasing dwell times can seriously degrade effectiveness. Mostly, the brute force approach is a loser’s game, especially against highly stealthy targets like the B-2A and F-22A. Much less stealthy targets yield some payoff.

The alternative of building sensors that can see the aircraft from directions or at wavelengths where it was not designed to be very stealthy is a much better game plan, and this is also where most current investment by the Russians and

Chinese is visible.

There are numerous ways in which this game can be played, and combinations of multiple techniques can be quite effective, especially against designs with poor or otherwise limited stealth performance. A technique that is often overstated in effectiveness is the use of networked radars and data fusion techniques, similar to the US Navy Cooperative Engagement Capability (CEC) system. CEC collects and simultaneously fuses tracking data from multiple shipboard search radars, the intent being to share tracking data across the fleet even if some targets are too distant to cleanly track for some radars, or below the radar horizon for others. In the CEC system a target 'blip' might be a fusion of intermittent or partial tracks from half a dozen different radars.

Defeating stealth targets using networking and data fusion presupposes that some radars can see the target some of the time, also that the target's stealth is considerably poorer in some directions compared to others, and finally that the target is visible by radars from varying aspects. Suffice to say a vehicle with good or excellent 'all aspect' stealth such as a B-2A will not be susceptible to this technique, since all of the radars in the network are equally blind. Even the F-22A is not particularly exposed, as its weakest areas in the beam aspect are not exposed long enough to seriously matter. Much more exposed are the compromised J-20, PAK-FA and F-35, as their side and rear aspects present many more tracking opportunities – making the front stealthy only works well if there is one enemy radar around that the fighter can point its nose at.

A networked data fusion system is thus not a panacea, but is potentially quite effective against stealth designs that do not have genuine 'all aspect' stealth capability, versus a marketed 'all aspect' capability. There are technical challenges in designing such systems, as the constituent radars must be built to not discard poor quality radar returns from point targets, in typical radars automatically rejected as 'false alarms'. Also, a lot of computing power is needed to sift and sort the collected data to determine which returns amount to a real target track. To date only the United States and Russia have demonstrated the ability to build such a system.

The alternative game plan to exploiting aspect limitations in target stealth shaping is to exploit wavelength limitations in target stealth shaping. This area has been the focus of most Russian and Chinese activity in CVLO systems design. This approach relies on the basic physics of stealth shaping, where a

straight edge or flat facet can only reflect sharply in one direction, if its geometrical size is larger than two or more wavelengths. A straight edge or flat facet which reflects the radar illumination away in a tight beam (technically a ‘lobe’) must be many wavelengths in size. If not, its reflection smears out over a wide range of angles, making it easier to detect.

In stealth fighters this effect is most prominent, as their size puts hard limits on the wavelengths where their forward and aft fuselages can still cleanly bounce illumination away. Typically performance that is reasonable in the 3 GHz decimetre wavelength S-band degrades with varying rapidity as the wavelength increases through the L-band, UHF-band down to the metre wavelength VHF-band.

Air Defence Systems

S-400 Triumf (Triumph) / SA-21

In the late 20th and early 21st century the following trends became apparent in the development of air and space attack weapons:

- development of low and extremely low flight altitudes,
- sharp reduction in their visibility in the basic physical fields through the integrated use of stealth technology,
- increase in the number of air threats in air defense weapons operations areas through the use of unmanned vehicles,
- equipping all air attack weapons with highly effective EW equipment, — use of precision guided weapons,
- growth in production and adoption of non-strategic ballistic missiles, primarily tactical and theater missiles, as well as the assimilation of production of medium-range ballistic missiles by some countries.

An opportunity to analyze the potential of the most effective air attack weapons became available also as a result of their use during operations in Iraq and Yugoslavia. The need to effectively accomplish the aerospace defense missions in these circumstances became the focal point in developing the new generation Triumph versatile and common mobile long-range air defense missile system (ADMS).

This system relied on the following design concepts:

- open architecture of the system providing the opportunity to enhance its capabilities, with modular design of the system assets,
- multi-functionality of the system and the air defense systems of various levels on the basis of the system components,
- possibility of using the system assets both to defend administrative and industrial installations and task forces,
- possibility of deploying the system launchers aboard naval vessels,
- possibility of using SAMs, which are already in service with the armed forces,

- high mobility and transportability of the system assets,
- high efficiency of the system in counter-fire and jamming conditions.

The mobile multi-channel ADMS system developed using these principles is intended to engage all types of current and future ECM aircraft, AEW&C aircraft, reconnaissance planes, including those that are part of the reconnaissance-strike systems, strategic aircraft carrying air-launched missiles, cruise missiles, tactical, theater and medium range ballistic missiles and other air attack weapons in a severe ECM environment. It should be noted that this system can selectively operate using several types of missiles having different weight-dimensional characteristics and launch ranges, thereby establishing layered defense.

All combat assets of the Triumph system are mounted on self-propelled wheeled all-terrain chassis, have built-in self-contained power supply, orientation and survey control, communications and life support systems. In addition, provision is made for using ADMS assets in specialized shelters, with removal of equipment containers of the multifunctional radar, command and control post, and radar system from their self-propelled chassis.

The full time to deploy the system from marching position and bring its assets to operational readiness is 5 to 10 minutes. Prime developer of the Triumph ADMS is Almaz-Antey concern, which is also responsible for the development of the systems command and control post, multifunctional radar system, launch automation equipment for launchers, electronic equipment for missile and algorithmic software.

Among its developers are also Fakel Design Bureau (missiles development); Research Institute of Instrumentation (acquisition radar system for the systems command post), and Special Engineering Design Bureau (launchers developer).

S-400 Triumf/SA-21 (**Figure 9-16**), mobile multi-channel air defense missile system, is a system of a new generation to effectively engage practically all the modern and future air attack weapons, including the medium range ballistic missiles.

A high effectiveness of the system combat use has been provided due to the optimal solution of the problems related to interaction (coordination of combat

actions) with the other air defense missile complexes, air defense missile systems and air defense missile/gun complexes in a complicated tactical situation as well as to the integration of S-400 Triumf into the air defense of the foreign customer.

High performance characteristics of the system have been obtained after increasing appreciably a range of the system radar equipment, introducing the new modes of scanning, employing different modes of radiation and signal processing and using the new 48N6E3 surface-to-air missiles. S-400 Triumf incorporates:

30K6E is an administration system which manages eight battalions. The 55K6E is a command and control centre based on the Ural-532301. The 91N6E is a panoramic radar detection system (range 600 km) with protection against jamming which is mounted on an MZKT-7930. The S band system can track 300 targets. Six battalions of 98ZH6E surface-to-air missile systems (an independent combat system) can track no more than six targets on their own, with an additional two battalions if they are within a 40-kilometre (25 mi) range. The 92N6E (or 92N2E) is a multi-functional radar with a 400-kilometre (250 mi) range which can track 100 targets. The 5P85TE2 launcher and the 5P85SE2 on a trailer (up to 12 launchers) are used for launch. The 48N6E, 48N6E2, 48N6E3, 48N6DM, 9M96E, 9M96E2 and the ultra-long-range 40N6E are authorized by a Russian presidential decree. According to the Russian government, the S-400 utilises an active electronically scanned array.

Optional elements of the S-400 (98ZH6E) include the 15I6ME–98ZH6E, with coverage of 30, 60 and 90 km beyond the 30K6E coverage. The 96L6E has a 300-kilometre (190 mi) detection range. The 40B6M is housing for the 92N6E or 96L6E radar. The Protivnik-GE is an anti-stealth UHF radar with a 400-kilometre (250 mi) range. The Moscow-1 passive sensor is 2 1⁄2 times more effective than the Protivnik, with a 400-kilometre (250 mi) range. Orion for a target-designation on-the-air defence system, and the Avtobaza-M and Orion+ Avtobaza adds high-precision detection. The 1RL220BE versions were reportedly were used for jamming. The 400-kilometre (250 mi)-range S-200D Dubna (SA-5c) missiles and S-300 P-family radar systems can be used without additional command-and-control centres. S-300 (SA-20A, SA-20B) missiles may also be guided. A-50 and A-50U aircraft provide early warning and command-and-control target designation.

The 30K6E control system can be integrated with the S-400 Triumph 98ZH6E system; the S-300PMU2 (through the 83M6E2 control system); the S-300PMU1 (through the 83M6E control system); the Tor-M1 through the Ranzhir-M battery-command post; the Pantsir-S1 through the lead battery vehicle. The Protivnik-GE and Gamma-DE radars, integrated with the 92H6E radar system, enables communication between each battery with Baikal-E senior command posts and similar types; nearby 30K6E, 83M6E and 83M6E2 administration systems; the Polyana-D4M1 command post; fighter-aircraft command post, and mobile long-range radars. The Nebo-M system is designed to hunt the F-35 joint-strike fighter. The system's VHF component provides sector search and tracking, with the X- and L-band components providing fine-tracking capability. Good placement of the radars relative to the threat axis enables the L- and X-band components to illuminate the incoming target from angles where the target RCS is sub-optimal. Attempts to jam the Nebo-M would be problematic, since all the radars have passive angle track capability against jammers; jamming permits passive triangulation of the target using three angle-track outputs. The RLM-S and RLM-D have better elevation-tracking accuracy than the RLM-M, and the Nebo M should be capable of producing high-quality tracks suitable for mid-course guidance of modern surface-to-air missiles and trajectory guidance of legacy SAMs.

The Gamma-C1E SHF mobile radar station has a 300-kilometre (190 mi) detection range. The Nebo VHF mobile radar station and the Resonance-NE radar station have a detection range of 1,200 kilometres (750 mi) and 65 kilometres (40 mi) to a height of 500 metres (1,600 ft). All Nebo-family locators are doubled for army air defence. During the 1970s, the long-range mobile UHF 5H87 and SHF 5H69 low-altitude locators were used. A 1980s goal was detection at a height of 10 metres (33 ft) at a distance of 40 km 25 mi).

For export to foreign customers, with the purpose of integrating existing customer air defence systems, additional work on improvement of the 30K6E administration system for information technology pairing with anti-kets is in progress.

Additional equipment including the external power supply facilities, group SPTA sets, radar 96L6E, training/ operating missiles and towers for the antennas of the multifunction radars and 96L6E radar to improve detection of the low-altitude targets. Maintenance complex incorporating an air servicer, a unified compressor station, a mobile vehicle-mounted repair workshop and other

equipment.

One system comprising up to 8 battalions can control up to 72 launchers, with a maximum of 384 missiles (including missiles with a range of less than 250 km (160 mi)). The missiles are fired by a gas system from the launch tubes up to 30 metres into the air before the rocket motor ignites, which increases the maximum and decreases the minimum ranges. In April 2015, a successful test firing of the missile was conducted at an airborne target at a range of 400 km (250 mi); TELs carrying the long-range 40N6 may only be able to hold two missiles instead of the typical four due to its larger size. Another test recorded a 9M96 missile using an active radar homing head, reached a height of 56 km. All the missiles are equipped with directed explosion warhead, which increases the probability of complete destruction of targets. In 2016, Russian anti-aircraft missile troops received new guided missiles for S-300 and S-400 defense systems. Anti-aircraft missile system, designed to destroy aircraft, cruise and ballistic missiles, it can also be used against ground objectives. The S-400 is able to intercept cruise missiles out to a range of about 40 km due to their low altitude flight paths.

S-400 ammunition includes the 48N6E3 and 48N6E2 air-to-surface missiles. The 48N6E surface-to-air missiles may be also used. The 48N6E and 48N6E2 missiles are similar to those the Favorit air defense missile system employs.

A new 48N6E3 SAM has been developed by upgrading the 48N6E2 SAM. Upgrade of the engine by using a solid propellant grain with the higher energetic characteristics offered an opportunity to expand the engagement zone at the outer boundary and to increase the employed engagement zones of the ballistic missiles.

Upgrade of the missile payload, i.e. a radio fuse with the controlled warhead has enhanced effectiveness of engagement of the high-speed, small and maneuvering targets, also providing for high probability of initiation of the high-explosive war payload of the ballistic targets, including the medium-range ballistic missiles flying at a speed of up to 4800 m/s.

In November 2015, the deployment of S-400 was reported in Syria, along with the contingent of Russian troops and other military hardware in the course of the air campaign conducted by the Russian forces on the side of the Syrian government. The first S-400 system was reportedly installed at Hmeimim Air

Base in Latakia Governorate. Between April and July 2017, a second S-400 system was deployed 13 km northwest of Masyaf, Hama Governorate.

S-300 / SA-10

The origins of this system date back to the 1960s. Anti-aircraft missile systems developed by that time suffered many flaws - insufficient range, poor target kill effectiveness, and engagement of aircraft, whose capabilities grew almost every year, was becoming increasingly difficult. This was confirmed during actions in Vietnam and the Middle East, where Soviet SA-2/S-75 and SA-3/S-125 passed the most severe test in super-extreme climatic conditions, while repelling real air attacks.

A comprehensive assessment of the air threat growth prospects carried out by experts from leading research institutes and design bureaus in the mid-1960s, using the lessons learned, led them to conclude that an all-new air defense missile system was required to solve the air defense tasks, capable of simultaneously firing at several targets flying in a wide range of speeds and altitudes, repelling massive air attacks from different directions.

By the late 1960s, these searches helped define the basic requirements for a system, which later received the designation S-300P/SA-10 (**Figure 9-17**). These requirements included the engagement and destruction of new generation aircraft, cruise missiles and tactical ballistic missiles. On 27 May 1969, the CPSU Central Committee and USSR Council of Ministers passed a resolution authorizing the beginning of this work, whose degrees of novelty and promise were at the level of the most significant domestic military-technical programs.

The main developer in charge for the overall system was CDB ALMAZ (general designer B.V.Bunkin) and missile developer was EDB Fakel (general designer P.D. Grushin). Even the first assessments showed that the successful development of this system was possible only through the assimilation of new materials and technologies by industry, widespread use of electronic integrated circuits and digital technology in the systems circuitry base, maximum automation of the basic combat functions, application of improved methods to guide missiles onto the target. The main mission of the system under development - to be capable of tracking and destroying several targets at the same time (for example to provide multi-channel operation as opposed to the single-channel S-75 and S-125) — required the use of a multifunction phased

array radar and multiple missile launchers.

On a par with the performance specifications, among the main criteria the S-300P developers were guided by were also the minimum number of required personnel and equipment pieces to reduce the system life-cycle cost, as well as the achievement of the characteristics necessary to repel air threats, whose emergence was expected in the coming decades.

The 5V55 missile developed for the S-300P also fully met these criteria. Its development relied upon analysis of all previous experience with similar efforts, accommodated many of the trends in missile technology available at that time, embodied the most advanced design, manufacturing and testing technologies.

For example, a number of innovative technical solutions were used during development of the 5V55. The use of a transport & launch container (TLC), in which the whole life-cycle of the missile was to take place — from assembly at a plant to launch — occupied one of the central places among them. In turn, the requirement for a high rate of fire led to a number of decisions aimed at minimizing the duration of prelaunch operations and time to target. Central among these was the use, for the first time for this type of missiles, of a forced vertical launch from TLC. This helped greatly increase the rate of fire of the system, since in this case all the missiles were directly on the launcher and ready for immediate launch; this allowed an effective all-around engagement of enemy aircraft and missiles flying in from different directions.

With such a launch, the sustainer engine of the 5V55 starts at an altitude of 20 to 25 meters. This minimizes the effects of the gas jet on the nearby components of the system. For a quick turn toward a target after the engine start, the missile is equipped with a special gas dynamic system. The first variant of the S-300 entered service with the Air Defense Forces in 1979. A more improved version designated S-300 PMU was adopted in the mid-1980s. Increased the cross-country capacity was one of its features : in this version all the system components were carried by a MAZ-543M tractor truck and their deployment from a marching order to ready-for-launch position took a mere 5 minutes.

In the mid-1980s, the S-300PMU was one of the most advanced weapons in the world. However, the progress achieved by this time in electronic technology, the emergence of new materials at the disposal of designers and process engineers made possible a significant increase in system performance. Of

particular significance was the possibility of an almost twofold increase in the engagement range against aerial targets, with virtually the same missile dimensions and launch weight.

The missile for the new S-300 PMU1 version received the designation 48N6E and was also capable of effectively engaging almost all the existing and future aircraft and helicopters, cruise missiles, air-to-surface missiles, and short-range ballistic missiles. Moreover, the S-300 PMU1 was favorably distinguished from similar systems by its efficiency, mobility and reliability in operation. Such a versatility of the system resulted from its optimal structure and high performance of its constituent assets, whose capabilities fully met its information needs and ensured the absolute operational self-sufficiency, including for establishing mobile defense against cruise and ballistic missiles. An important advantage of the system was also a high adaptability of its assets to stay on alert for prolonged time, which was especially critical in the period preceding the outset of hostilities.

The system is in constant evolution since has considerable growth potential, including as regards significant expansion of the engagement zones for aerodynamic and ballistic air attack weapons and their kill effectiveness. These qualities have been realized to a large extent in the S-300 PMU2 Favorit air defense missile system.

Favorit mobile multi-channel air defense missile system can ensure highly effective defense against the attacks of aviation, strategic cruise, aeroballistic, operational/tactical and tactical ballistic missiles and other air attack weapons in a complicated and an intensive electronic countermeasures environment.

Favorit forms a grouping of Air Defense that incorporates one 83M6E2 control element and up to six S-300PMU2 air defense missile systems. Using the special integration devices, the ground interrogator of the corresponding standard and the communication equipment, FAVORIT can adapt to any air defense systems of the country, also for interaction with their weapons, control systems and information equipment.

Favorit retained its best design and unique technical solutions and also the basic principles of functioning used in the S-300PMU1 ADMS and 83M6E control system (CS).

FAVORIT was created after upgrade of its predecessors – S-300 PMU1

ADMS and 83M6E CS. The performances and operational characteristics were thus enhanced to a level corresponding to the modern and future air attack weapons.

This was achieved due to the improvement of the devices and the software/algorithmic support of the system equipment and usage of the 48N6E2 SAM with the updated payload and new attached radar systems.

Favorit 83M6E2 control systems are designed to ensure control over the combat activities of the S-300PMU2 air defense systems (complexes). The radar reconnaissance is provided by the acquisition radar. Based on the data coming from the higher control equipment, the acquisition radar and controlled air defense missile systems, the 54K6E2 combat control point automatically processes and displays the radar reconnaissance data, selects the targets for engagement, generates and transmits the target designation data to the air defense systems, controls their combat actions, documents the combat actions of the air defense missile and control systems in real time. Besides, the combat control point transmits information to the higher control equipment on the combat statuses and combat actions of the air defense missile system and ensures interaction with the adjacent control systems and command posts.

The 83M6E2 control system includes:

- combat control center 54K6E2;
- acquisition radar 64N6E2;
- maintenance facilities including the SPTA sets, external power supply sources and vehicles;
- supplementary equipment including the antenna-mast assemblies and repeaters to extend a radio communication range.

S-300PMU2 ADMS / SA-20

The S-300PMU2/SA-20 mobile multi-channel air defense missile systems can destroy the air attack weapons both using the data from the 83M6E2 control system and when operating independently.

Each S-300PMU2 air defense missile system (complex) includes combat assets, maintenance facilities and supplementary equipment.

Combat assets incorporate:

- one illumination and guidance radar 30N6E2 (IGR);
- up to 12 launchers 5P85SE2 (chassis mounted) or launchers 5P85SE2 (trailer-mounted with a prime mover);
- surface-to-air missiles (SAM) 48N6E2 and 48N6E in the container-launchers.

Maintenance facilities include operation and missile storage equipment, SPTA sets and sets of operational documentation, external power supply sources of the illumination and guidance radar and control point, soft mock-ups and training/ operating missiles and vehicles.

The supplementary equipment includes the 96L6E radar (all-altitude radar), mobile towers for the IGR antenna posts and the 96L6E radar antenna devices (to improve acquisition of low-altitude targets) and maintenance and repair facilities for the air defense missile systems, vehicles, survey vehicle, unified compressor station and air servicer and cable-laying vehicle.

ALTEK-300 training system can be also attached as a supplementary element to FAVORIT ADMS for teaching and training the crews of the 83M6E2 CS and S-300PMU2 ADMS without resorting to the combat weapons of the air defense system. FAVORIT delivery set (also supplementary) and its is determined by the Customer.

30N6E2 IGR is the main radar element in the S-300PMU2 ADMS. It performs automatic radar search for a target either against the target designation data or independently (also using all-altitude radar), acquisition, identification, classification, lock-on and automatic tracking of the targets, automatic solution of the launch tasks, placing missiles for preparation, automatic lock-on and tracking of the targets in response to the radio signals of the airborne transponders and their guidance towards the tracked targets. The IGR also provides for detonation of the missile warheads and automatic assessment of the combat operation results.

Missiles are launched on commands from the illumination and guidance radar. A missile is guided at a target by the “track-via-missile” method. Once locked on by the IGR, the missile is automatically guided at its initial phase at a target by the radio command method and at its final phase, by the semi-active radar homing using the data of the target tracked by the missile radar direction finder that receives the signals of the target illuminated by the IGR. These target

data are transmitted from the SAM to the IGR to be correlated there with the data of the same target that the IGR tracks. After correlation of data, the IGR forms and transmits control commands to the missile to correct its flight trajectory.

The SAM warhead is detonated by the semi-active radio fuse in response to the special return signal from the target illuminated by the IGR. The ballistic missile warhead detonation is initiated in this case and the aerodynamic target is destroyed.

The ADMS combat assets are mounted on a cross-country highly mobile wheeled chassis. They are equipped with navigation, survey control and orientation, autonomous power supply, tele-code and voice communication and life support equipment. ADMS assets can be transported by any kinds of transport means.

S-300V/SA-12

The 9K81 S-300V Antey-300 (Russian 9K81 С-300В Антей-300 – named after Antaeus, NATO reporting name SA-12 Gladiator/Giant) varies from the other designs in the series. (**Figure 9-18**). This complex is not part of the S-300, including is designed by another developer. It was built by Antey rather than Almaz, and its 9M82 and 9M83 missiles were designed by NPO Novator. The V suffix stands for Voyska (ground forces). It was designed to form the top tier army air defence system, providing a defence against ballistic missiles, cruise missiles and aircraft, replacing the SA-4 Ganef. The "GLADIATOR" missiles have a maximum engagement range of around 75 km (47 mi) while the "GIANT" missiles can engage targets out to 100 km (62 mi) and up to altitudes of around 32 km (20 mi). In both cases the warhead is around 150 kg (330 lb). The S-300VM (Antey 2500) is an upgrade to the S-300V. It consists of a new command post vehicle, the 9S457ME and a selection of new radars. These consist of the 9S15M2, 9S15MT2E and 9S15MV2E all-round surveillance radars, and the 9S19ME sector surveillance radar. The upgraded guidance radar has the Grau index 9S32ME. The system can still employ up to six TELARs, the 9A84ME launchers (up to 4 × 9M83ME missile) and up to 6 launcher/loader vehicles assigned to each launcher (2 × 9M83ME missile each). An upgraded version, dubbed S-300V4 will be delivered to the Russian army in 2011.

The Antey-2500 complex is the export version developed separately from the

S-300 family and has been exported to Venezuela for an estimated export price of 1 billion dollars. The system has one type of missile in two versions, basic and amended with a sustainer stage that doubles the range (up to 200 km (120 mi), according to other data up to 250 km (160 mi)) and can simultaneously engage up to 24 aircraft or 16 ballistic targets in various combinations.

9K37 BUK / SA-17

Development of the Buk (9K37)/SA-17 (**Figure 9-20**, **Figure 9-21**) battlefield self-propelled SAM system commenced in accordance with the Resolution of the CPSU Central Committee and USSR Council of Ministers dated 13 January 1972 and provided for cooperation between the main developers and manufacturers that had earlier developed the Kub system.

The Buk missile system was designed to surpass the 2K12 Kub in all parameters, and its designers, including its chief designer Ardalion Rastov, visited Egypt in 1971 to see Kub in operation. Both the Kub and Buk used self-propelled launchers developed by Ardalion Rastov. As a result of this visit, the developers came to the conclusion that each Buk transporter erector launcher (TEL) should have its own fire control radar, rather than being reliant on one central radar for the whole system as in Kub. The result of this move from TEL to transporter erector launcher and radar (TELAR) was development of a system able to shoot at multiple targets in multiple directions at the same time.

In 1974 the developers determined that although the Buk missile system is the successor to the Kub missile system, both systems could share some interoperability. The result of this decision was the 9K37-1 Buk-1 system. Interoperability between Buk TELAR and Kub TEL meant an increase in the number of fire control channels and available missiles for each system, as well as faster entry of Buk system components into service. The Buk-1 was adopted into service in 1978 following completion of state trials, while the complete Buk missile system was accepted into service in 1980 after state trials took place between 1977 and 1979.

The naval variant of the 9K37 "Buk", the 3S-90 "Uragan," was developed by the Altair design bureau under the direction of chief designer G.N. Volgin. The 3S-90 used the same 9M38 missile as the 9K37, though the launcher and associated guidance radars were exchanged for naval variants. After the 9S-90 system was tested, between 1974 and 1976 on the Kashin-class destroyer Provorny, it was accepted into service in 1983 on the Project

956 Sovremeniy-class destroyers.

No sooner had the 9K37 "Buk" entered service than the Central Committee of the CPSU authorised the development of a modernised 9K37 which would become the 9K37M1 Buk-M1, adopted into service in 1983. The modernisation improved the performance of the system radars, its "probability of kill" and its resistance to electronic countermeasures (ECM). Additionally a non-cooperative threat classification system was installed, relying on analysis of returned radar signals to purportedly identify and clearly distinguish civilian aircraft from potential military targets in the absence of IFF.

Another modification to the Buk missile system was started in 1992 with work carried out between 1994 and 1997 to produce the 9K37M1-2 Buk-M1-2, which entered service in 1998. This modification introduced a new missile, the 9M317, which offered greater kinematic performance over the previous 9M38, which could still be used by the Buk-M1-2. Such sharing of the missile type caused a transition to a different GRAU designation, 9K317, which has been used independently for all later systems. The previous 9K37 series name was also preserved for the complex, as was the "Buk" name. The new missile, as well as a variety of other modifications, allowed the system to shoot down ballistic missiles and surface targets, as well as enlarging the "performance and engagement envelope" (zone of danger for potential attack) for more traditional targets like aircraft and helicopters. The 9K37M1-2 Buk-M1-2 also received a new NATO reporting name distinguishing it from previous generations of the Buk system; this new reporting name was the SA-17 Grizzly. The export version of the 9K37M1-2 system is called "Ural" (Russian: "Урал"), this name has also been applied to M2, at least to early, towed, export versions.

Combat service

- Abkhaz authorities claimed that Buk air defense system was used to shoot down four Georgian drones at the beginning of May 2008.
- Analysts concluded that Georgian Buk missile systems were responsible for downing four Russian aircraft - three Sukhoi Su-25 close air support aircraft and a Tupolev Tu-22M strategic bomber - in the 2008 South Ossetia war. U.S. officials have said Georgia's SA-11 Buk-1M was certainly the cause of the Tu-22M's loss and contributed to the losses of the three Su-25s. According to some analysts, the loss of four aircraft is surprising and a heavy toll for Russia given the small size of Georgia's military. Some have also pointed out, that Russian electronic counter - measures systems were

apparently unable to jam and suppress enemy SAMs in the conflict and that Russia was, surprisingly, unable to come up with effective countermeasures against missile systems it had designed. Georgia bought these missile systems from Ukraine which had an inquiry to determine if the purchase was illegal.

- The system was used in the downing of the Boeing 777-200ER Malaysia Airlines Flight 17, on 17 July 2014, in eastern Ukraine, which resulted in 298 fatalities. Evidence included missile fragments found on site including pieces of warhead stuck in the wreckage as well as non-explosive parts of the missile with serial number remnants. Missile fragments were recovered from the bodies of the flight crew.
- On April 14, 2018, American, British, and French forces launched a barrage of 105 air-to-surface and cruise missiles targeting eight sites in Syria. According to a Russian source, twenty-nine Buk-M2E missiles launched in response allegedly destroyed twenty-four incoming missiles. However, the American Department of Defense stated no Allied missiles were shot down (deja vue in previous conflicts).
- In May 2018, during Operation "House of Cards", the Israeli Air Force allegedly hit a Syrian Buk system. No independent source confirmed this.

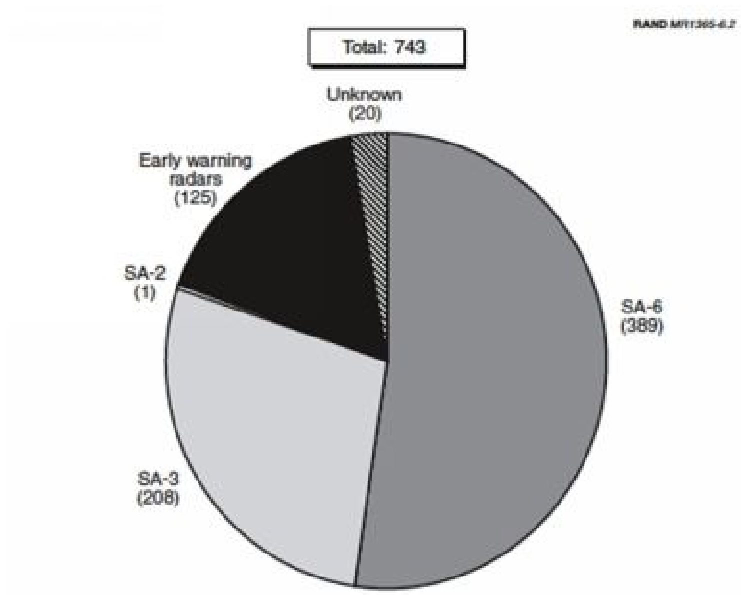


Figure 9-1: A total of 815 SAMs were fired at NATO aircraft, of which 665 were radar guided SA-3 and SA-6 rounds. Out of them, F-16CG and F-117A were downed and several other aircraft sustained damage through the hit or ear miss. Many SAM shots were unguided due to the radar shutting down to avoid HARM shots. Statistically, minor number of missiles hit the targets but the overall effect of launching shall take in consideration repelling the atacks. (Source: AWOS Fact Sheet via www.ausairpower.net).

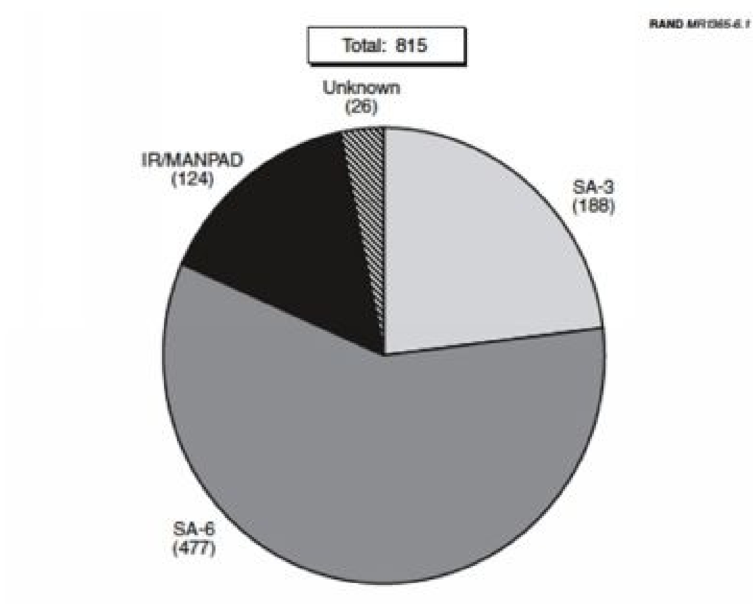


Figure 9-2: NATO expended a total of 743 AGM-88 HARM anti-radiation missile rounds, launched by EA-6B Prowlers, F-16CJ Weasels and Tornado ECRs. The most notable aspect of this chart is that more than 50% of HARMs were fired at mobile SA-6 batteries, which suffered the lowest attrition of any Serbian radar guided SAM type. Minimum 22 HARM missiles were launched against the 3rd battalion without any hit. (Source: AWOS Fact Sheet via www.ausairpower.net).

Figure 9-3: Laser bomb craters after attack on UNK (left) and burning equipment (right). (Source: Authors)

Figure 9-4: Heavy damaged UNK cabin (Source: Authors)

Figure 9-5: Decoys - wooden MiG-29 (left) and passenger car masked as an armored vehicle (right). (Source: Authors)

Figure 9-6: Modernized towed Low-Blow (UNV-125)
(Source: Almaz-Antey)

Figure 9-7: Mounted Low-Blow
(Source:Cenrex)

Figure 9-8: Polish Newa SC Anaconda launcher based on T-55 chassis
(Source: Cenrex)

Figure 9-9: Cuban SA-3 TELs
(Source: Vestnik PVO)

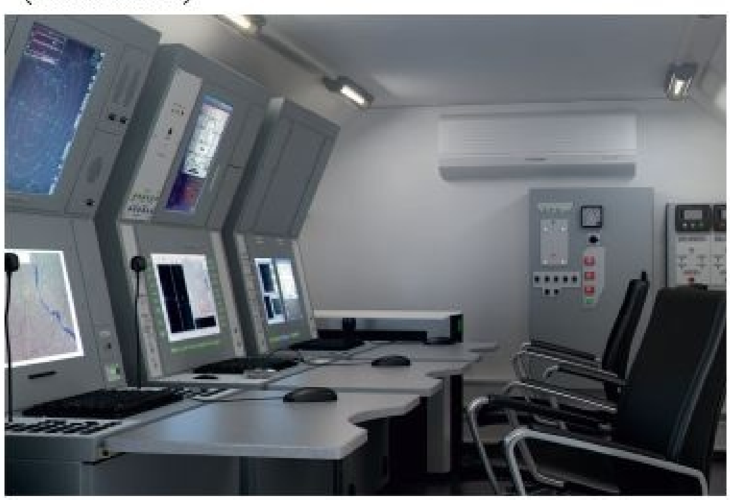


Figure 9-10: UNK operator stations using LCD displays
(Source:Almaz-Antey)

Figure 9-11: F-117A scrapping). (Source: techsob.com)

Figure 9-12: F-22 Raptor (Source: USAF)

Figure 9-13: F-35 Lighting II (Source:USAF)

Figure 9-14: NEBO-M new Russian counter stealth radar (side view). (Source: Vitaly Kuzmin)

Figure 9-15: NEBO-M new Russian counter stealth radar (front view). (Source: Vitaly Kuzmin)

Figure 9-16: S-400/SA-21. (Source: Almaz-Antey)

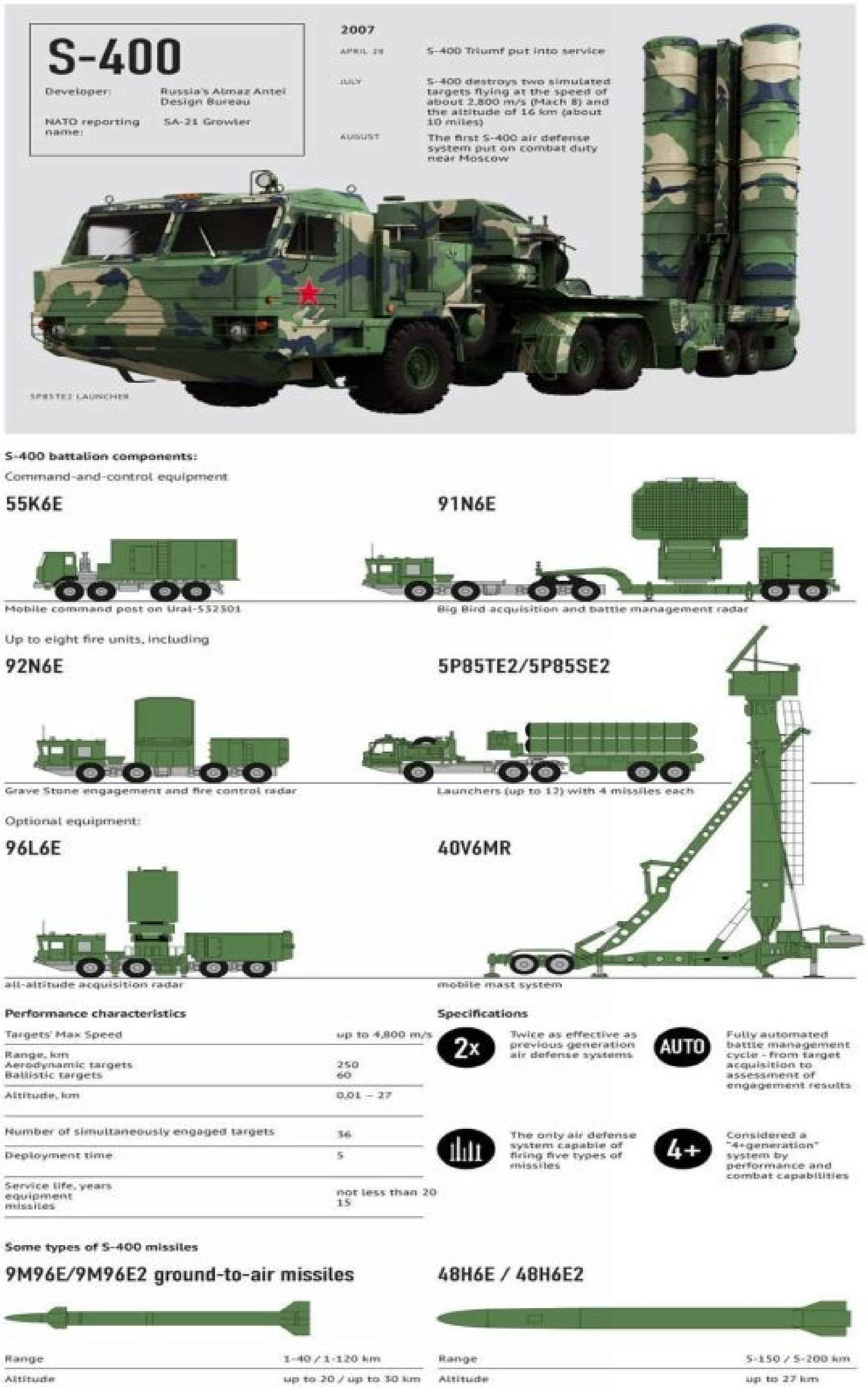

S-400
Developer: Russia's Almaz Antei Design Bureau
NATO reporting name: SA-21 Growler
2007
APRIL 28
S-400 Triumf put into service
JULY
S-400 destroys two simulated targets flying at the speed of about 2,800 m/s (Mach 8) and the altitude of 16 km (about 10 miles)
AUGUST
The first S-400 air defense system put on combat duty near Moscow
5P85TE2 LAUNCHER
S-400 battalion components:
Command-and-control equipment
55K6E
Mobile command post on Ural-532301
91N6E
Big Bird acquisition and battle management radar
Up to eight fire units, including
92N6E
Grave Stone engagement and fire control radar
5P85TE2/5P85SE2
Launchers (up to 12) with 4 missiles each
Optional equipment:
96L6E
all-altitude acquisition radar
40V6MR
mobile mast system
Performance characteristics
Targets' Max Speed
up to 4,800 m/s
Range, km
Aerodynamic targets
Ballistic targets
250
60
Altitude, km
0,01 – 27
Number of simultaneously engaged targets
36
Deployment time
5
Service life, years
equipment
missiles
not less than 20
15
Specifications
2x
Twice as effective as previous generation air defense systems
AUTO
Fully automated battle management cycle - from target acquisition to assessment of engagement results
The only air defense system capable of firing five types of missiles
4+
Considered a "4+generation" system by performance and combat capabilities
Some types of S-400 missiles
9M96E/9M96E2 ground-to-air missiles
Range
1-40 / 1-120 km
Altitude
up to 20 / up to 30 km
48H6E / 48H6E2
Range
5-150 / 5-200 km
Altitude
up to 27 km

Figure 9-17: S-300/SA-10 components (Source: RosOboronEksport)

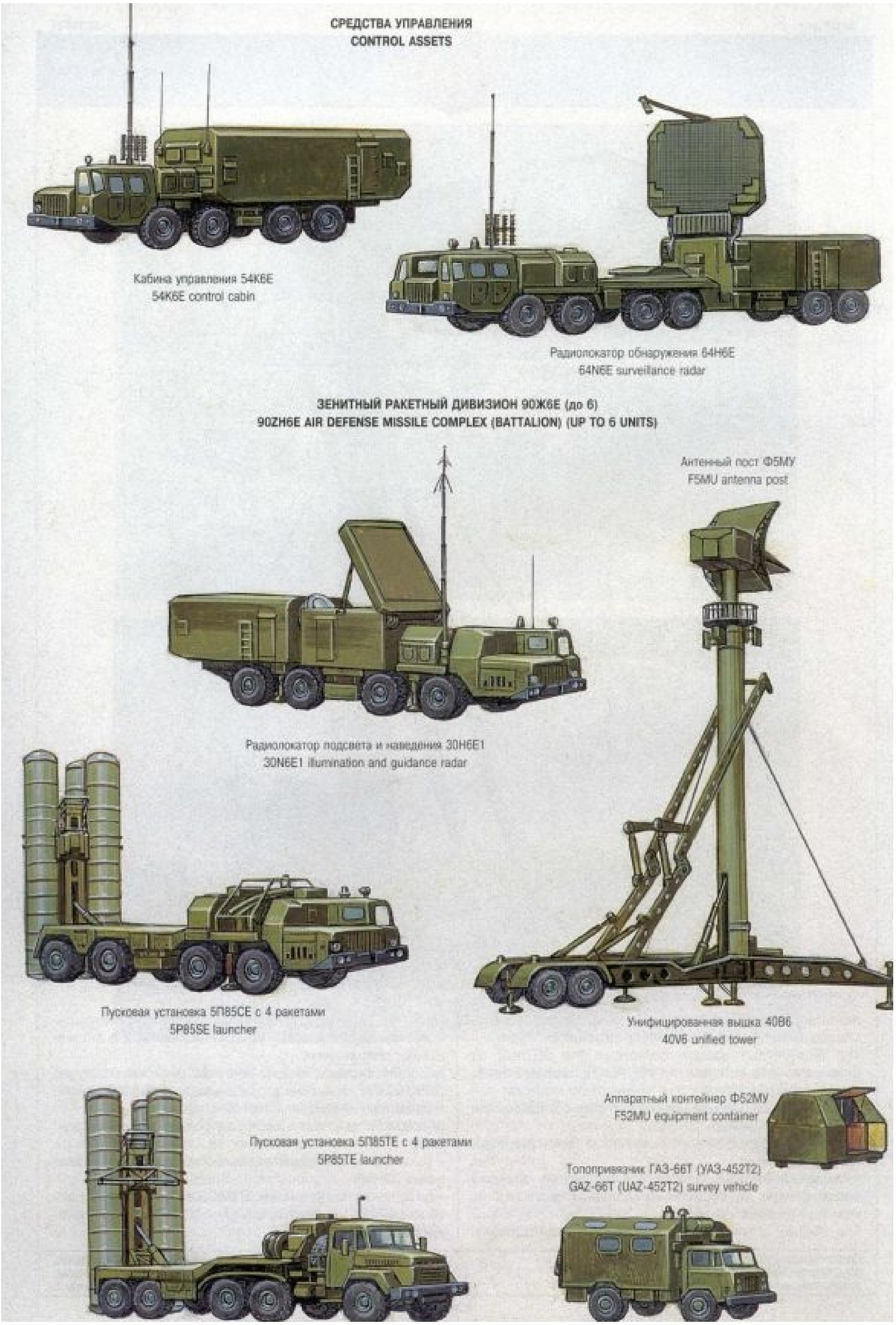

СРЕДСТВА УПРАВЛЕНИЯ
CONTROL ASSETS
Кабина управления 54К6Е
54K6E control cabin
Радиолокатор обнаружения 64Н6Е
64N6E surveillance radar
ЗЕНИТНЫЙ РАКЕТНЫЙ ДИВИЗИОН 90Ж6Е (до 6)
90ZH6E AIR DEFENSE MISSILE COMPLEX (BATTALION) (UP TO 6 UNITS)
Антенный пост Ф5МУ
F5MU antenna post
Радиолокатор подсвета и наведения 30Н6Е1
30N6E1 illumination and guidance radar
Пусковая установка 5П85СЕ с 4 ракетами
5P85SE launcher
Унифицированная вышка 40В6
40V6 unified tower
Аппаратный контейнер Ф52МУ
F52MU equipment container
Пусковая установка 5П85ТЕ с 4 ракетами
5P85TE launcher
Топопривязчик ГАЗ-66Т (УАЗ-452Т2)
GAZ-66T (UAZ-452T2) survey vehicle

Figure 9-18: S-300/SA-10 on Moscow V-E parade. (Source: Vitaly Kuzmin)

Figure 9-19: S-300V/SA-12 Army tracked mobile air defence system of 202 brigade . (Source: Vitaly Kuzmin)

Figure 9-20: SA-17 Gudly BUK in Moscow Patriot park. (Source: Vitaly Kuzmin)

Figure 9-21:BUK (front) and S-300 launchers (rear) in Moscow Patriot park. (Source: Vitaly Kuzmin)

NATO codification system

- SA-1 "Guild" (S-25 Berkut)
- SA-2 "Guideline" (S-75 Dvina/Volkhov/Desna)
- SA-3 "Goa" (S-125 Neva)
- SA-4 "Ganef" (9M8 Krug)
- SA-5 "Gammon" (S-200 Volga)
- SA-6 "Gainful" (3M9 Kub/Kvadrat)
- SA-7 "Galosh" and "Grail" (9K32 Strela-2)
- SA-8 "Gecko" (9K33 Osa)
- SA-9 "Gaskin" (9K31 Strela-1)
- SA-10 "Grumble" (S-300P/PS/PT)
- SA-11 "Gadfly" (9K37 Buk)
- SA-12 "Gladiator" and "Giant" (S-300V)
- SA-13 "Gopher" (9K35 Strela-10)
- SA-14 "Gremlin" (9K36 Strela-3)
- SA-15 "Gauntlet" (9K330/9K331/9K332 Tor)
- SA-16 "Gimlet" (9K310 Igla-1)
- SA-17 "Grizzly" (9K37 Buk-M1-2)
- SA-18 "Grouse" (9K38 Igla)
- SA-19 "Grison" (2K22 Tunguska)
- SA-20 "Gargoyle" (S-300PM/PMU Favorit)
- SA-21 "Growler" (S-400 Triumf)
- SA-22 "Greyhound" (Pantsir-S1)
- SA-23 "Gladiator/Giant" (S-300VM "Antey-2500")
- SA-24 "Grinch" (9K338 Igla-S)
- SA-25 "9K333 Verba" (9K333 Verba)

US DoD has a different designations for naval to surface-to-air missiles (SAN series) with Soviet designations. However, these are not standard NATO names. NATO uses the regular SA series for naval SAM US DoD refers to them by these names:

- SA-N-1 Goa (4K90 Volna) [SA-3]
- SA-N-2 Guideline (M-2 Volkhov-M) [SA-2]
- SA-N-3 Goblet (4K60/4K65 Shtorm)

- SA-N-4 Gecko (9M33 Osa-M) [SA-8]
- SA-N-5 Grail (9K32 Strela-2) [SA-7]
- SA-N-6 Grumble (S-300F Fort) [SA-10]
- SA-N-7 Gadfly (9M38/9M38M Uragan)[[SA-11]
- SA-N-8 Gremlin" (9K34 Strela-3) [SA-14]
- SA-N-9 Gauntlet (3K95 Kinzhal) [SA-15]
- SA-N-10 Grouse (3M38 Igla) [SA-18]
- SA-N-11 Grison (3M87 Kashtan) [SA-19]
- SA-N-12 Grizzly (3K37 Smerch/Shtil) [SA-17]
- SA-N-14 Grouse (9K38 Igla) [SA-18]
- SA-N-20 Gargoyle (S-300FM) [SA-20]

Glossary

The following are typical glossary of terms which can be found in radar, electronic warfare, stealth and air defence fields. Not all of them are used in this book but it is worth to have them at one place so it may help reader to understand the meaning of abbreviations and terminology often used in these fields. There are many other terms and abbreviations which meaning is explained in the text so in majority of cases, they are not included in this glossary.

Absorption - Dissipation of energy of electromagnetic waves, sound, and light waves into other forms of energy because of interaction with matter. Absorption characteristics of specific materials are used as blankets, coatings, or structural and surface materials for aircraft to reduce effective radar cross-sections.

Acoustic jamming - The deliberate radiation of mechanical or electro-acoustic signals with the objectives of obliterating or obscuring signals which the enemy is attempting to receive, and of deterring enemy weapon systems.

Active homing guidance - A system of homing guidance in which both the source for illuminating the target, and the receiver for detecting the energy reflected from the target as the result of illumination, are carried within the missile.

Airborne early warning and control - Air surveillance and control provided by airborne early warning vehicles that are equipped with search and height finding radar and communications equipment for controlling weapons.

Airborne interceptor (Al) - A manned aircraft used for identification and/or engagement of airborne objects. (An Al may or may not be equipped with radar to assist in the interception.)

Airborne Warning and Control System (AWACS) - An aircraft suitably equipped to provide control, surveillance, and communications capability for strategic defense and/or tactical air operations.

Air defense - All defensive measures designed to destroy attacking enemy aircraft or missiles in the earth's envelope of atmosphere, or to nullify or reduce the effectiveness of such attack.

Air surveillance radar (ASR) - A radar displaying range and azimuth that is normally employed in a terminal area as an aid to approach and departure

control.

Air-to-air missile (AAM) - A missile launched from an airborne carrier at a target above the surface.

Air-to-surface missile (ASM) - A missile launched from an airborne carrier to impact on a surface target.

Amplifier - An electronic circuit usually used to obtain amplification of voltage, current, or power.

Angle jamming - A deception jamming technique used to deny azimuth and elevation information to a TTR by transmitting a jamming pulse similar to the radar pulse, but with modulation information out of phase with the returning target azimuth modulation information.

Antenna - A device used for transmitting or receiving RF energy. The function of the antenna during transmission is to concentrate the radar energy from the transmitter into a shaped beam that points in the desired direction. During reception, or listening time, the function of the antenna is to collect the returning radar energy, contained in the echo signals, and deliver these signals to the receiver. Radar antennas are characterized by directive beams that are usually scanned in a recognizable pattern. The primary radar antenna types in use today fall into three categories: parabolic, Cassegrain, and phased array antennas.

Antiaircraft artillery (AAA) - Guns used to shoot unguided projectiles at airborne aircraft. Usually used in the air defense system.

Antiradiation missile (ARM) - A missile that homes passively on a radiation source.

Area defense - The concept of locating defense units to intercept enemy attacks, remote from, and without reference to, individual vital installations, industrial complexes, or population centers.

Automatic gain control (AGC) – 1. A feature involving special circuitry designed to maintain the output of a radio, radar, or television receiver essentially constant, or to prevent its exceeding certain limits, despite variations in the strength of the incoming signal. In a radio receiver, in particular, though something of a misnomer, also known as automatic volume control.

2. A self-acting compensating device that maintains the output of a transmission system constant with narrow limits, even in the face of wide variations in the attenuation of the system.

3. A radar circuit that prevents saturation of the radar receiver by long blocks of receiver signals, or by a carrier modulated at low frequency.

Automatic search jamming - An intercept receiver and jamming transmitting system that automatically searches for and jams enemy signals of specific radiation characteristics.

Automatic tracking - Tracking in which a system employs some mechanism, e.g., servo or computer, to automatically follow some characteristics of the signal.

Azimuth -

1. the direction of a celestial object from the observer, expressed as the angular distance from the north or south point of the horizon to the point at which a vertical circle passing through the object intersects the horizon.
2. the horizontal angle or direction of a compass bearing.

Azimuth – Search – Command to start searching with the tracking and/or fire control radar in designated direction.

Azimuth resolution - The ability of a radar to distinguish two targets in close azimuth proximity and distance.

Backlobe - The portion of the radiation pattern of an antenna that is oriented 180° in relation to the main beam. The antenna backlobe is a result of diffraction effects of the reflector and direct leakage through the reflector surface.

Bandwidth - The range of frequencies within which performance, with respect to some characteristics, falls with specific limits (i.e., the width of frequency of a

barrage noise package).

Beam rider - A missile guided by an electronic beam.

Beamwidth - The width of a radar beam measured between lines of half-power points on the polar pattern of the antenna. This width is measured at the 3 dB points.

Bistatic radar - A radar where the transmitting and receiving antennas are separated by a considerable distance. Bistatic operation provides several advantages for its user. The covert positioning of the receivers poses problems for a potential attacking force since ELINT techniques locate the transmitter not the receiver. The proper placement of jamming assets is difficult, since the receiving sites are unknown. In addition, if a stand-off jammer is directed at the transmitter, its effectiveness in the direction of the covert receiver is diminished. Jammers not in the same beam as the wanted targets will be attenuated by the receiver's sidelobe protection and these targets will be more readily detected.

Chaff - Ribbon-like pieces of metallic materials or metalized plastic that are dispensed by aircraft to mask or screen other aircraft or to cause a tracking radar

to break lock. The foil materials are generally cut into small pieces for which the size is dependent upon the radar interrogation frequency (approximately 1/2 wavelength of the victim radar frequency). Being 1/2 wavelength long, chaff acts as a resonant dipole and reflects much of the energy back to the radar.

Chaff corridor - Operational technique of dropping large quantities of chaff

for a continuous period of time. This results in a “ribbon” or “stream” of returns many

miles long on radar scopes. The penetrating strike force can then use the resulting chaff corridor to mask its penetration.

Circular scan - The pattern generated by an antenna that is continuously rotating in one direction.

Clutter - Unwanted signals, echoes, or images on the face of a scope that interferes with the observation of desired signals. Also called noise. This tends to mask the true target from detection or cause a tracking radar to break lock.

Clutter elimination - The clutter eliminator circuit discriminates against any target echo that exceeds three times the transmitted pulse width, and will not display it

on the indicator. It is normally employed on the lower beams of a high frequency radar. This will allow targets above a preset signal strength to be presented, while the clutter (land) will be eliminated.

Command and control warfare (C2W) - The integrated use of operations security (OPSEC), military deception, psychological operations (PSYOP), electronic warfare (EW), and physical destruction, mutually supported by intelligence to deny information, influence, degrade, or destroy adversary C2 capabilities while protecting friendly C2 capabilities.

Command, control, communications, and computer systems (C4) - The process of, and means for, the exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the commander's mission.

Command guidance - A guidance system in which intelligence transmitted to the missile from an offboard source causes the missile to traverse a directed flight path.

Communications intelligence (COMlNT) - Intelligence derived from the interception of enemy communications signals.

Communications security (COMSEC) - The protection resulting from all measures designed to deny unauthorized persons information of value that might be derived from the possession and study of telecommunications, or to mislead unauthorized persons in their interpretation of the results of such possession and study. COMSEC includes: 1. Cryptosecurity; 2. transmission security; 3. emission security; and 4. physical security of communications security material and information.

1. ***Cryptosecurity*** - The component of communications security that results from the provision of technically sound cryptosystems and their proper use.

2. ***Transmission security*** - The component of communications security from

which all measures designed to protect transmissions from interception and exploitation by means other than cryptoanalysis.

3. ***Emission security*** - The component of communications security that results from all measures taken to deny unauthorized persons information of value that might be derived from intercept and analysis of compromising emanations from crypto equipment and telecommunications systems.

4. ***Physical security*** - The component of communications security that results from all physical measures necessary to safeguard classified equipment, material, and documents from access thereto or observation thereof by being within a friendly power.

Conical scan (CONSCAN) - A type of scanning in which the axis of the RF beam is tilted away from the axis of the reflector and rotated about it, thus generating a cone.

Cross-eye - A jamming technique used to produce angular errors in monopulse and other passive lobing radars. Jammer is a two-source interferometer that causes the phase front of the signal reaching the radar to be highly distorted. With such a technique, it is difficult for the radar to determine the points from which the transmissions are originating. Requires a high jam-to-signal ratio or the skin echo will show up in the pattern nulls.

Cross-gated CFAR - A CFAR technique employed to achieve the fast switching required for an optimum combination of normal and MTI modes. Here, the MTI video signals are used to "gate" on the normal video when the MTI indicates a target in clutter. CFAR action is achieved by the wideband as in the zero-crossing and Dicke fix CFARs.

CW jamming - The transmission of constant-amplitude, constant-frequency, unmodulated jamming signals to change the signal-to-noise ratio of a radar receiver.

Data link - A communications link which permits automatic transmission of information in digital form.

Deception - Those measures designed to mislead the enemy by manipulation, distortion, or falsification of evidence to induce him to react in a manner prejudicial to his interests. (See Electronic Deception, or Manipulative Deception.)

Deception jamming - Any means of jamming consisting of false signals that have similar characteristics to the victim radar thereby deceiving the operator into erroneous conclusions.

Decibel (dB) - A dimensionless unit for expressing the ratio of two values, the number of decibels being 10 times the logarithm to the base 10 of a power

ratio, or 20 times the logarithm to the base 10 of a voltage of current ratio. A power increase by 3 dB indicates a doubling of the original power.

(dBm) - Same as dBw except the reference level is one milliwatt instead of one watt.

(dBw) - Unit used to describe the ratio of the power at any point in a transmission system to a referenced level of one watt. The ratio expresses decibels above and below the reference level of one watt.

Defense suppression - A term applied to weapons systems that are intended to eliminate or degrade enemy detection, acquisition, or tracking equipment.

Doppler (effect) - Continuous wave (CW) Doppler radar modules are sensors that measure the shift in frequency created when an object moves. A transmitter emits energy at a specific frequency which, when reflected, can indicate both speed and direction of the target. When objects move closer to the Doppler source, they increase in shift (positive value), and when they move further away, they decrease in shift (negative value).

Doppler radar - A radar system that measures the velocity of a moving object by the apparent shift in carrier frequency of the returned signal as it approaches or recedes.

Downlink - The signal from a transponder beacon located on a surface-to-air missile (SAM) used to provide a traceable radar return for missile guidance.

Downlink jamming (DLJ) - Some command guidance missiles carry a beacon (downlink) which is used by the parent radar to track the missile. If this beacon reply can be hidden from the parent tracking radar, the missile guidance solution can be defeated. Hence, downlink (beacon) jamming is intended to screen the missile beacon signal from the parent radar's view.

Ducting - The bending of radar rays due to atmospheric conditions. Ducting can either extend radar coverage beyond normal line of sight or it can deny the radar picture above a duct. Ducting is also called Anomalous Propagation.

Dummy antenna - A device that has the necessary impedance characteristics of an antenna and the necessary power-handling capabilities, but does not radiate or receive radio waves. Note: In receiver practice, that portion of the impedance not included in the signal generator is often called a dummy antenna.

Dummy load (radio transmission) - A dissipative but essentially nonradiating substitute device having impedance characteristics simulating those of the substituted device. This allows power to be applied to the radar unit without radiating into free space.

Duplex - In radar, a condition of operation when two identical and interchangeable equipments are provided—one in an active state, and the other immediately available for operation.

Duplexer - A switching device used in radar to permit alternate use of the same antenna for both transmitting and receiving.

Duty cycle - The ratio of the time the transmitter is actually on versus the time it could be on in a given transmission cycle.

Dynamic range –

1. The difference, in decibels, between the overload level and the minimum acceptable signal level in a system or transducer. Note: The minimum acceptable signal level of a system or transducer is ordinarily fixed by one or more of the following: noise level, low-level distortion, interference, or resolution level.

2. Ratio of the specified maximum signal level capability of a system or component to its noise or resolution level, usually expressed in decibels.

Early warning radar - A radar set or system used near the periphery of a defended area to provide early notification of hostile aircraft approaching the area.

EA pod - A jamming system that is designed to be carried externally on an aircraft.

Effective radiated power (ERP) - Input power to antenna time multiplied by the gain of the antenna, expressed in watts.

Electromagnetic interference (EMI) - Any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades or limits the effective performance of electronic systems. EMI can be induced intentionally, by way of jamming, or unintentionally because of spurious emissions and modulations.

Electromagnetic pulse (EMP) - The generation and radiation in a transmission medium of a very narrow and very high-amplitude pulse of electromagnetic noise.

The term is associated with the high-level pulse because of a nuclear detonation and with an intentionally generated narrow, high-amplitude pulse for EA applications. In nuclear detonations, the EMP signal consists of a continuous spectrum with most of its energy distributed throughout the low frequency band of 3 to 30 kHz.

Electromagnetic radiation - Radiation made up of oscillating electric and magnetic fields and propagated with the speed of light. Includes gamma radiation, x-rays, ultraviolet, visible and infrared radiation, plus radar and radio waves.

Electromagnetic spectrum - The total range of frequencies (or wavelengths) over which any form of electromagnetic radiation occurs.

Electronic attack (EA) - The use of electromagnetic energy, directed energy, or antiradiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability. Action

taken to reduce the enemy’s effective use of the electromagnetic spectrum. EA is a division of electronic warfare (EW).

Electronic combat (EC) - Action taken in support of military operations against the enemy's electromagnetic capabilities. EC is task-oriented and includes electronic warfare (EW), command and control warfare (C2W), and suppression of enemy air defenses (SEAD).

Electronic protection (EP) - Active and passive means taken to protect personnel, facilities, and equipment from any effects of friendly or enemy employment of electronic warfare that degrade, neutralize or destroy friendly combat capability. EP is a division of electronic warfare (EW).

Electromagnetic deception - The deliberate radiation, reradiation, alteration, absorption, or reflection of electromagnetic radiations in a manner intended to

mislead an enemy in the interpretation of, or use of, information received by his electronic systems. There are two categories of electronic deception:

1. ***Manipulative deception*** - The alteration or simulation of friendly electromagnetic radiation to accomplish deception.

2. ***Imitative deception*** - The introduction of radiations into enemy channels that imitate his own emissions.

Electronic intelligence (ELINT) - The intelligence information product of activities engaged in the collection and processing for subsequent intelligence purposes of foreign, noncommunications, electromagnetic radiations emanating from other than nuclear detonations or radioactive sources.

Electronic jammers –

1. ***Expendable*** - A transmitter designed for special use such as being dropped behind enemy lines.

2. ***Repeater*** - A receiver-transmitter device that, when triggered by enemy radar impulses, returns synchronized false signals to the enemy equipment. The returned impulses are spaced and timed to produce false echoes or bearing errors in the enemy equipment. See Expendable and Repeater Jammers.

Electronic jamming - The deliberate radiation, reradiation, or reflection of electromagnetic energy with the object of impairing the use of electronic devices, equipment, or systems.

Electronic order of battle - A listing of all the electronic radiating equipment of a military force giving location, type function, and other pertinent data.

Electronic reconnaissance - Specific reconnaissance directed toward the collection of electromagnetic radiations. Examples:

COMINT Communications Intelligence

ELINT Electronic Intelligence

OPINT Optical Intelligence

RINT Radiated Intelligence

SIGINT Signal Intelligence

Electronic warfare (EW) - Military action involving the use of electromagnetic energy and directed energy to control the electromagnetic spectrum. EW has three divisions: electronic attack (EA), electronic protection (EP), and electronic warfare support (ES).

Electronic warfare support (ES) - Actions taken to search for, intercept, identify, and locate sources of intentional radiated electromagnetic energy for the purpose of immediate threat recognition. Surveillance of the electromagnetic spectrum that directly supports an operational commander's electromagnetic information

needs. ES is a division of EW.

Electro-optics (EO) - The interaction between optics and electronics leading to the transformation of electrical energy into light, or vice versa, with the use of an

optical device.

Electro-optic counter-countermeasures (EOCCM) - Actions taken to ensure the effective friendly use of the electro-optic spectrum despite the enemy's use of countermeasures in that spectrum.

Emission control (EMCON) –

1. The management of electromagnetic radiations to counter an enemy's capability to detect, identify, or locate friendly emitters for exploitation by hostile action.

2. Controlling the radiation of an active system to minimize detection by enemy sensors.

Endgame - The period of military engagement 3-5 seconds before missile impact.

Endgame countermeasures (EGCM) - Actions taken to defeat a tracking missile. This includes expendables, decoys, and maneuvers.

Equivalent - The command “**Equivalent**’ is to “turn off” the high frequency energy emission into the space, but not turn off the radar.

Expendable jammer - A nonrecoverable jammer. Early expendables were limited to chaff and flare deployments; however, various radiating jamming systems exist that use noise or repeater techniques. These are dispensed by aircraft or other delivery systems and are designed to disrupt or deceive a victim radar for a short period of time.

Extremely high frequency (EHF) - Frequencies in the range of 30 to 300 GHz.

False target - Radiated bundle of electromagnetic energy that is displaced in

time from the echo that creates a response in the receiver where no reflecting surface exists.

False target generator - Device for generating electromagnetic energy of the correct frequency of the receiver that is displaced in time from the reflected energy of the target.

Field of view (FOV) - The maximum solid angle visible by an optical or electrooptic system.

Fire control radar - Specialized radar systems used to locate and track airborne and surface targets, compute an optimum weapons firing point, and control the firing and sometimes guidance of its weapons.

FM-by-noise modulation - A method of frequency modulating with effective jamming method against AM and fix-tuned FM receivers. Not very effective against continuously tunable PFM receivers; careful tuning can defeat a great portion of the jamming signal. For this reason, FM-by-noise is not considered optimum as a type of modulation for jamming FM receivers.

FM jamming - Technique consisting of a constant amplitude RF signal that is varied in frequency around a center frequency to produce a signal over a band of frequencies.

Frequency spectrum - The entire range of frequencies of electromagnetic radiation.

G, g - Acceleration due to gravity (32.2 ft/sec2).

Gain (manual) - The receiver gain control allows the operator to vary the receiver sensitivity. It is not designed as an AJ feature; however, when properly employed it may greatly reduce the effects of jamming. The radar detection capability is also reduced by an equal amount.

Gain (transmission gain) - The increase in signal power in transmission from one point to another under static conditions. Note: Power gain is usually expressed in decibels.

Get the High Down – The command mean that the high voltage is turned off but the emitter is still working in the normal mode but there is no high energy emission into the space.

Ground controlled intercept (GCI) - Vectoring an interceptor aircraft to an airborne target by means of information relayed from a ground-based radar site that observes both the interceptor and target.

Guidance system (missile) - A system that evaluates flight information,

correlates it with target data, determines the desired flight path of the missile, and communicates the necessary commands to the missile flight control system.

Guided missile - An unmanned vehicle moving above the surface of the earth, whose trajectory of flight path is capable of being altered by an external or internal mechanism.

Height finder - A radar used to detect the angular elevation, slant range and height of objects in the vertical sight plane. An air defense ground radar used specifically to accurately determine aircraft altitude for tracking and ground controlled intercepts.

Hertz (Hz) - The unit of frequency, equal to one cycle of variation per second. It supersedes the unit cycle per second (cps).

High frequency (HF) - Frequencies from 3000 - 30,000 kHz.

Home-on-jam (HOJ) - A missile mode of operation in which a jamming signal is used to develop steering information for the missile to home in on the jamming

source.

Homing guidance - A system by which a missile steers itself toward a target by means of a self-contained mechanism which is activated by some distinguishing characteristics of the target.

Identification, friend or foe (IFF) - A system using radar transmission to which equipment carried by friendly forces automatically responds, for example, by emitting pulses, thereby distinguishing themselves from enemy forces. It is the primary method or determining the friendly or unfriendly character of aircraft and ships by other aircraft and ships, and by ground forces employing radar detection equipment and associated identification, friend or foe units.

Image frequency - An undesired input frequency capable of producing the selected frequency by the same process. NOTE: An image frequency is a frequency which differs from, but has a certain symmetrical relationship to, that

which a superheterodyne receiver is tuned. Consequently, the image frequency can be mistakenly accepted and processed as a true frequency by the receiver.

Image jamming - Jamming at the image frequency of the radar receiver. Barrage jamming is made most effective by generating energy at both the normal operating and imaging frequency of the radar. Image jamming inverts the phase of the response and is thereby useful as an eagle deception technique. Not effective if the radar uses image rejection.

Imitative deception - The introduction of radiations into enemy channels which imitates their own emissions.

Imitative jamming - The jamming technique of transmitting a signal

identical to the original guidance signal.

Infrared (IR) - That portion of the frequency spectrum lying between the upper end of the millimeter wave region and the lower (red) end of the visible spectrum. In wavelength, the IR lies between 0.78 and 300 microns; in frequency, it lies between one and 400 terahertz (THz).

Infrared counter-countermeasures (IRCCM) - Actions taken to effectively employ our own infrared radiation equipment and systems in spite of the enemy's actions

to counter their use.

Infrared countermeasures (IRCM) –

1. Countermeasures used specifically against enemy threats operating in the infrared spectrum.

2. Actions taken to prevent or reduce the effectiveness of enemy equipment and tactics employing infrared radiation.

Intercept point - A computed point in space toward which an interceptor is vectored to complete an interception.

Interference (electronic) - An electrical or electromagnetic disturbance that causes undesirable responses on electronic equipment. Electrical interference refers specifically to interference caused by the operation of electrical apparatus that is not designed to radiate electromagnetic energy.

Intermediate frequency (IF) –

1. A fixed frequency to which all carrier waves are converted in a superheterodyne receiver.

2. A frequency to which a signaling wave is shifted locally as an intermediate step during transmission or reception.

3. A frequency resulting from the combination of the received signal and that of the local oscillator in a superheterodyne receiver.

Intermediate frequency jamming - Form of CW jamming that is accomplished by transmitting two CW signals separated by a frequency equal to the center frequency of the radar receiver IF amplifier.

Interrogator - A device used to transmit pulse-coded challenges to an IFF transponder and then evaluates the pulse-coded reply for identification purposes.

Intrapulse modulation repeater - A classified deception jamming technique.

Intrusion –

1. The entry of a nonfriendly aircraft or system into friendly air space.

2. The intentional interference in a communication system by which the intruder attempts to confuse, delay, or cause error by the selective introduction of additional data.

Jammer - A device used to deprive, limit, or degrade the use of

communications or radar systems. Radio frequency jammers include noise, discrete frequency repeater, and deceptive equipment.

Jamming-to-signal (J/S) ratio - The relative power ratio of jamming to the radar return signal at the radar antenna. The inverse of the signal-to-jamming ratio.

Jam strobe - Also called JAVA (jamming amplitude versus azimuth). A circuit that generates a marker on the PPI to indicate signal strength as a function of bearing.

It does this by sampling the jamming intensity once each repetition period. Besides showing the direction of the jammer, it also indicates the severity of main beam and sidelobe jamming.

Jet engine modulation (JEM) - Modulation present in the radar returns received from a jet aircraft, caused by the rotation of the fan or turbine blades of the aircraft's engines.

Klystron - A very stable microwave amplifier that provides high gain at good efficiency. This is accomplished by velocity modulating (accelerating a beam of electronics flowing from its cathode to its anode.

Laser target designation - The use of a laser to direct a light beam onto the target so that appropriate sensors can track or home on the reflected energy.

Light amplification by stimulated emission of radiation (LASER) - A process of generating coherent light. The process uses a natural molecular (and atomic) phenomenon whereby molecules absorb incident electromagnetic energy at specific frequencies. It then stores this energy for short but usable periods, then releases the stored energy as light at particular frequencies, and in an extremely narrow frequency band.

Lobe - One of the three-dimensional sections of the radiation pattern of a directional antenna bounded by 1-2 cones of nulls.

Lobe-on-receive-only (LORO) - Mode of operation consisting of transmitting on one antenna system and receiving the reflected energy on another system (TWS,

conical, or monopulse).

Look-down, shoot-down - Refers to an air interceptor (Al) equipped with a pulse Doppler radar, or a radar that has a moving target indicator (MTI) feature, that can detect and lock-on to a target within ground return clutter enabling the Al to track and shoot the target.

Look-through –

1. When jamming, a technique by which the jamming emission is interrupted irregularly for extremely short periods to allow monitoring of the victim signal during jamming operations.

2. When being jammed, the technique of observing or monitoring a desired signal during interruptions in the jamming signals.

Low frequency (LF) - Frequencies from 30 - 300 kHz.

Low power spread spectrum radar - A low power, high duty cycle radar whose spectrum is spread 100 MHz or more. Since this radar has a broad output spectrum and a high duty cycle, neither time nor frequency can be effectively used to resolve these signals. This leaves direction as the prime method of resolution. The spectrum of these radars is spread over the bandwidth by any of the pseudo random noise modulating techniques commonly used in communications. Techniques such as bi-phase modulation, quaternary phase modulation, chirp, random frequency jumping, etc., may be used to spread either a CW signal or a very high duty cycle signal. Such signals have a very good range resolution—approximately equal to the reciprocal of the bandwidth.

Magnetron - A radar microwave device whose operation is based on the motion of electrons (AC) under the influence of combined electric and magnetic fields.

Mainlobe - The lobe of a transmitting or receiving antenna centered on the directivity axis of the antenna.

Manipulative deception - The alteration or simulation of friendly electromagnetic radiations to accomplish the deception.

Jamming - the deliberate radiation, reradiation, or reflection of electromagnetic energy with the intent of impairing the use of electronic devices, equipment, or systems being used by the enemy.

Intrusion - the intentional insertion of electromagnetic energy into transmission paths in any manner with the objective of deceiving operators or causing confusion.

Medium frequency (MF) - Frequencies from 300 to 3,000 kHz.

Micron - A unit of length equal to a micrometer (10-6 meters).

Microwave amplification by stimulated emission or radiation (MASER) - A lownoise, radio-frequency amplifier. The emission of energy stored in a molecular or

atomic system by a microwave power supply is stimulated by the input signal.

Microwave communications - Line-of-sight communications, the frequency of which is higher than 300 MHz.

Millimeter waves - Frequencies (30 GHz to 300 GHz) in the millimeter portion of the electromagnetic spectrum.

Miss distance - The distance measured between the closest paths of a target and interceptor (i.e., aircraft and missile). One objective of self-protection

jamming systems is to increase the miss distance to avoid destruction if missile launch cannot be prevented.

Missile approach warning system (MAWS) - A system used to detect and provide warning of approaching missiles. MAWS may be partitioned into active MAWS

and passive MAWS.

1. ***Active missile approach warning system (AMAWS)*** - Generally employs pulse Doppler radar as its sensor. This radar is able to discern a moving target in stationary or slow-moving background clutter.

2. ***Passive missile approach warning system (PMAWS)*** - An ultraviolet (UV) or infrared-based detector system with the ability to detect and distinguish threat missiles from surrounding clutter and non-lethal missiles.

Modulation - The variation of amplitude, frequency, or phase of an electromagnetic wave by impressing another wave on it.

Modulator - A device (such as an electron tube) for modulating a carrier wave or signal for the transmission of intelligence of some sort.

Monopulse - A method of pulse generation that allows the simultaneous determining of azimuth, elevation and range, and/or speed from a single puIse.

Monopulse radar - A radar using a receiving antenna system having two or more partially overlapping lobes in the radiation patterns. Sum and difference channels in the receiver compare the amplitudes or the phases of the antenna outputs to determine the angle of arrival of the received signal relative to the antenna boresight. A well-designed monopulse tracking system will achieve a more accurate track under conventional jamming techniques than on the skin return.

Certain monopulse trackers are susceptible to angular jamming techniques such as skirt and image jamming. Techniques such as “CROSS EYE” are designed to attack all monopulse tracking systems. Monopulse deception is a major area of advanced R&D with no clear “best technique” yet in sight.

Moving target indicator (MTI) - A radar presentation that shows only targets that are in motion. Signals from stationary targets are subtracted out of the return signal by the output of a suitable memory circuit.

Multiband radar - Radar that simultaneously operates on more than one frequency band through a common antenna. This technique allows for many sophisticated forms of video processing and requires that a jammer must jam all channels simultaneously.

Noise –

1. Any unwanted disturbance within a dynamic electrical or mechanical system, such as undesired electromagnetic radiation, and any transmission

channel or device.

2. Uncontrolled random disturbances that arise in a guided missile system because of various physical phenomena.

Noise jamming - Direct (straight) AM or FM noise on a carrier frequency that has a highly variable bandwidth for the purpose of increasing (saturating) the radar receiver's noise level.

Oscillator - Electronic circuit or device capable of converting direct current (DC) into alternating current (AC) at a frequency determined by the inductive and the

capacitive constants of the oscillator.

Over-the-horizon radar - A radar system that makes use of the ionosphere to extend its range of detection beyond line-of-sight. Over-the-horizon radars may be either forward scatter or backscatter systems.

Passive detection and tracking - By combining azimuth data on jamming strobes from several stations, intersections are obtained which indicate the position of the jammers. The number of ghosts can be reduced by increasing the number of friendly stations and obtaining elevation angles of strobes when available.

Passive electronic countermeasures - Electronic countermeasures based on the reflection, absorption or modification of the enemy's electromagnetic energy.

This distinction between active and passive countermeasures is not currently used, but is based on the presence or absence of an electronic transmitter.

Passive homing guidance - A system of homing guidance in which the receiver in the missile uses radiations only from the target.

Phased array radar - Radar using many antenna elements that are fed out-of-phase to each other. The direction of the beam can be changed as rapidly as the phase relationships (usually less than 20 μsec). Thus, the antenna remains stationary while the beam is moved electronically. The use of many antenna elements allows for very rapid and high directivity of the beam(s) with a large peak and/or average power.

Point defense - The defense of specified geographical areas, cities, and vital installations. One distinguishing feature of point defense missiles is that their guidance information is received from radars located near the launching sites.

Polarization - The direction of an electrical field is considered the direction of polarization. When a half-wave dipole antenna is horizontally oriented, the emitted wave is horizontally polarized. A vertical polarized wave is emitted when the antenna is erected vertically.

Pulse Doppler radar - A highly complex radar system that employs a very high pulse repetition frequency (usually 10,000 PPS or higher) to reduce “blind

speeds” and measure the Doppler frequency shift to resolve target velocity. Pulse Doppler is applied principally to radar systems requiring the detection of moving targets in a ground clutter environment. It uses pulse modulation to achieve higher peak power, greater range, less susceptibility to unfriendly detection, and enhanced range resolution.

Pulse duration - The time in microseconds that the radar set is transmitting RF energy. Generally, the greater the pulse duration, the higher the average power, but the poorer the range resolution. Also known as pulse width. More technically, it is the time interval, measured at the half-amplitude points, from the leading edge to the trailing edge of a pulse.

Radar absorbent material (RAM) - Material used as a radar camouflage device to reduce the echo area of an object.

Radar beacon - A receiver-transmitter combination that sends out a coded signal when triggered by the proper type of pulse enabling determination of range and bearing information by the interrogating station or aircraft.

Radar cross section - The equivalent area intercepted by a radiated signal and, if scattered uniformly in all directions, produces an echo at the radar receiver equal to that of the target. Typical radar cross sections of aircraft vary from one to over 1,000 square meters. The RCS of ships may exceed 10,000 square meters.

Radar definition - The accuracy with which a radar obtains target information such as range, azimuth, or elevation.

Radar homing - Homing on the source of a radar beam.

Radar homing and warning (RHAW) - Typically consists of an airborne, wideband video receiver designed to intercept, identify, and display the direction to pulse type emitters.

Radar resolution - A measure of a radar's ability to separate targets that are close together in some aspect of range, azimuth, or elevation into individual returns.

Radar warning receiver (RWR) - A receiver onboard an aircraft that analyzes the hostile radar environment and determines radar threat by type, frequency, relative bearing, and relative distance. The threat is displayed to the aircrew by means of display lights, video symbols, and aural tones.

Radio frequency (RF) - Electromagnetic energy radiated at some frequency.

Radio frequency interference - An unintentional interfering signal capable of being propagated into electronic equipment, usually derived from sources outside the system.

Range - The distance from one object to another.

Range tracking - Pulse radars measure the time difference between radar

pulse transmission and echo reception. The range gate is positioned at a range where the target is expected. The receiver is blanked off except during the period where the range gate is positioned. Range tracking may occur at the leading edge of the return pulse or between ON and OFF gates.

Resolution - The ability of a system to distinguish between two adjacent objects and to display them separately.

SAM - Surface-to-air missile.

Scan - The process of directing a beam of RF energy successively over a given region, or the corresponding process in reception.

Scan interval - The time interval from the peak of one mainlobe in a scan pattern to the peak of the next mainlobe.

Scan period - The time period of basic scan types (except conical and lobe switching) or the period of the lowest repetitive cycle of complex scan combinations. The basic unit of measurement is degrees/mils per second or seconds per cycle.

Scan type - The path made in space by a point on the radar beam, for example, circular, helical, conical, spiral, or sector.

Search –

1. A term applied to that phase of radar operation when the lobe, or beam of radiated energy, is directed in such a way to search for targets in the area.

2. A systematic examination of space to locate and identify targets of interest.

Sector scan - A scan in which the antenna sweeps back and forth through a selected angle.

Self-protection jamming - Jamming to protect the vehicle upon which the jammer is deployed.

Semiactive radar homing - Semiactive homing guidance combines principles from both the beam rider and the active radar homing missile. Track on the target is established by the AI's radar; the missile is launched when the target comes within its effective range. During missile flight, the Al maintains track on the target. Radar returns from the target are received by the missile. Guidance commands are generated within the missile from the radar returns.

Sidelobe - Part of the beam from an antenna, other than the mainlobe. Sidelobe gain is usually less than mainlobe gain. Given that the mainlobe radiates most of the power at zero degrees azimuth, sidelobes inherently radiate significant power in the direction of +20°, 90°, and 150° relative to the mainlobe.

Sidelobe jamming - Jamming through a sidelobe of the receiving antenna in an attempt to obliterate the desired signal received through the mainlobe of the

receiving antenna at fixed points.

Sidelobe suppression - The suppression of that portion of the beam from a radar antenna other than the mainlobe.

Signal intelligence (SIGINT) - Intelligence derived from the interception of enemy communications and noncommunication signals. A generic term that includes

both COMINT and ELINT.

Signal-to-jamming ratio (S/J) - The ratio of the signal power to the jamming power or intentional interference at some point in the system. This ratio is often expressed in decibels.

Signal-to-noise ratio (S/N) - Ratio of the power of the signal to the power of the noise.

Signature - The set of parameters that describes the characteristics of a radar target or an RF emitter and distinguishes one emitter from another. Signature parameters include the RF of the carrier, the modulation characteristics (typically the pulse modulation code), and the scan pattern.

Super high frequency (SHF) - Frequencies from 3 to 30 GHz.

Support jamming - A tactic by which aircraft carrying electronic jamming equipment orbit at a safe distance from the enemy threat defenses or fly escort with the strike force for the primary purpose of screening them from the threat radars.

Suppression of enemy air defenses (SEAD) - That activity which neutralizes, destroys, or temporarily degrades enemy air defense systems in a specific area by using physical attack, deception, and/or electronic warfare.

Surface-to-air missile (SAM) - A missile launched from a surface launcher at a target above the surface.

Sweep jammer - Electronic jammer that sweeps a narrow band of electronic energy over a broad bandwidth.

Synthetic aperture radar (SAR) - A high-resolution ground mapping technique in which advantage is taken of the forward motion of a coherent pulsed radar to synthesize the equivalent of a very long sidelooking array antenna from the radar returns received over a period of up to several seconds or more.

Target acquisition - The detection, identification, and location of a target in sufficient detail to permit the effective employment of weapons.

Terminal guidance –

1. The guidance applied to a guided missile between mid-course and arrival in the vicinity of the target.

2. Electronic, mechanical, visual, or other assistance given to aircraft pilots

to facilitate arrival at, operation within or over, landing upon or departure from an air landing or air drop facility.

Terminal threat - The weapon systems, generally near a target, used to directly engage an aircraft in order to destroy it.

Terrain-avoidance radar - An airborne radar that provides a display of terrain ahead of low-flying aircraft to permit horizontal avoidance of obstacles.

Terrain-following radar (TFR) - An airborne radar that provides a display of terrain ahead of low-flying aircraft to permit manual control, or signals for automatic

control to maintain constant altitude above the ground.

Threshold - The minimum value of a signal that can be detected by a system or sensor under consideration.

Time-of-arrival (TOA) - A method of locating a distant pulse emitter by measuring the difference in the time-of-arrival of its pulses at three separate locations. This method is also called Inverse LORAN.

Track –

1. A series of related contacts displayed on a plotting board.
2. To display or record the successive positions of a moving object.
3. To lock onto a point of radiation and obtain guidance from it.
4. To keep a gun properly aimed, or to continuously point a target-locating instrument at a moving target.
5. The actual path of an aircraft above, or a ship on, the surface of the earth. The course is the path that is planned; the track is the path that is taken.

Tracking - The continuous monitoring of range, velocity, or position of a target in space from a reference position. This is accomplished via radar and/or optical means.

Tracking radar - A radar that measures the range, azimuth, elevation, and/or velocity of the target and provides data that may be used by the fire control computer to determine the target path and predict its future position.

Track-on-jam - A method of passive target tracking using the jamming signal emitted by the target.

Track-while-scan (TWS) radar - Although it is not really a tracking radar in the true sense of the word, it does provide complete and accurate position information for missile guidance by using two separate beams produced by two separate antennas on two different frequencies. The system uses electronic computer techniques whereby raw data are used to track an assigned target, compute target velocity, and predict its future position while maintaining normal sector scan.

Ultra high frequency (UHF) - Frequencies from 300 to 3,000 MHz.

Very high frequency (VHF) - Frequencies from 30 to 300 MHz.

Very low frequency (VLF) - Frequencies from 3 to 30 kHz.

Video frequency –

1. A band of frequencies extending from approximately 100 Hz to several MHz.

2. The frequency of the voltage resulting from television scanning. Range from zero to 4 MHz or more.

Warning receiver - A receiver with the primary function of warning the user that his unit is being illuminated by an electromagnetic signal of interest.

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[1] The word **RADAR** came from using the capitalized letters of the phrase **RA**dio **D**etection **A**nd **R**anging. The wide spread military use of it during WWII changed the progress of the war from the Battle of Britain to the Pacific. It later became an indispensable navigation and traffic control system for civilian purposes.